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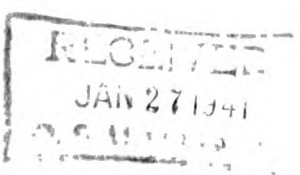
GAS EXPLOSIONS IN BUILDINGS: THEIR CAUSE AND PREVENTION



BY

D. J. PARKER AND C. W. OWINGS

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

GAS EXPLOSIONS IN BUILDINGS: THEIR CAUSE AND PREVENTION[1]

By D. J. Parker[2] and C. W. Owings[3]

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INTRODUCTION

Because of its convenience and availability, natural gas (and to a much less extent manufactured gas) is being used more generally throughout

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the country for domestic and industrial purposes. With this use, specific and little-recognized hazards have arisen owing principally to the fact that the public and the consumer lack knowledge of the explosive property of this fuel.

During the past 7 years gas explosions have occurred in public and private buildings with loss of more than 300 lives and injury to many others. Such appalling catastrophes can and will be prevented if and when the necessary precautions are taken in the construction of buildings and the installation and maintenance of gas lines and gas appliances, plus adequate supervision, inspection, and education.

Many potential hazards have existed unrecognized in industry until revealed by accident. The same condition has existed in the general community supplied with combustible gases.

The gas industry is now passing through an unfortunate and unhappy experience somewhat similar to that of the bituminous coal-mining industry some years ago in connection with the prevention of coal-dust explosions. Such disasters have been minimized and now occur relatively seldom. With the same interest and effort, gas explosions in buildings undoubtedly will become rare, also, if they are not eliminated entirely.

On request, engineers of the Bureau of Mines have studied thoroughly and comprehensively a number of gas explosions in buildings in various parts of the country, and it is believed that publication of the results of such investigations, with indication of the lessons to be learned and specific recommendations for the prevention of similar occurrences, will be of general value.

This report summarizes the results of these investigations and includes other pertinent data in the hope that in the future definite responsibility will be inescapable on the part of individuals or groups whose duty it is to safeguard the lives of the public, including school children and teachers, from the hazards of gas explosions.

The Bureau of Mines was asked to inspect all the school buildings in Butte and Great Falls, Mont., and the theaters in Butte; 66 buildings were inspected, and the findings are included in this report. The purpose was to ascertain whether construction and maintenance of school buildings approximated those of the New London (Tex.) school that had been involved in an explosion shortly before.

PROPERTIES OF NATURAL AND MANUFACTURED GAS

Before going into detail regarding the several explosions that have been investigated, it appears desirable to discuss briefly the properties of natural and manufactured gas and warning agents used in natural gas.

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ERRATUM

GAS EXPLOSIONS IN BUILDINGS: THEIR CAUSE AND PREVENTION

By D. J. Parker and C. W. Owings

Page 3, paragraph 7, page 28, paragraph 3, and page 30, paragraph 5 of Summary of Recommendations should read:

> The Bureau of Mines recommends the use of ethyl mercaptan as one of the most effective agents for emergency detection of leaks in natural gas systems. The temporary addition of a concentration of about 5 pounds per million cubic feet of gas is effective in indicating house leaks; to indicate leaks in underground mains and service lines, the amount should be increased to and maintained for several days at approximately 50 pounds per million cubic feet of gas.

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Natural Gas

Natural gas is virtually odorless, tasteless, and colorless; it is lighter than air and nontoxic, except when carbon monoxide is formed by incomplete combustion. Taking the weight of air as 1.00, the weight of natural gas is about 0.65. The explosive range when mixed with air ranges from about 4.80 to 15.00 percent; that is, if the percentage of natural gas in air is below 4.80 or above 15.00 the gas-air mixture is nonexplosive. The most violent explosion occurs when approximately 9 percent of gas is present in the gas-air mixture.

Manufactured Gas

Manufactured gas has a characteristic disagreeable odor, is somewhat lighter than air, and is extremely poisonous because of its relatively high content of carbon monoxide. The percentage of carbon monoxide ranges from about 6 to 12 percent, but 10 percent is believed to be a fair average except where carbureted water gas is employed. Its poisonous properties can be appreciated better when it is remembered that slight symptoms develop when the concentration of carbon monoxide in the air reaches 0.05 percent, and 0.20 percent is definitely dangerous.

The explosive range of gas-air mixtures - 6 to 36 percent - is much wider than that for natural gas.

Malodorants

As natural gas has very little odor a person may not detect its presence readily by the sense of smell. It is now common practice, therefore, in many parts of the country to introduce into natural gas a chemical with a noxious odor to give warning of leaks from gas lines or from defective gas appliances.

A malodorant now in use apparently is highly effective where gas leaks occur inside buildings. However, when the leak is outside a building, beneath the ground, and the gas migrates laterally through the ground into basements or unventilated subfloors of buildings, this malodorant is ineffective because it is absorbed or filtered out or its effect is otherwise destroyed by going through the ground.

All natural gas should be treated with a malodorant or stench that retains its disagreeable characteristics after passing through the ground. Manufactured gas does not require a warning agent because of its inherent malodorant properties, which are not destroyed or lost by migration of this gas through the ground.

The Bureau of Mines recommends the use of ethyl mercaptan as one of the most effective ~~warning~~ agents for natural gas. An initial concentration of 5 pounds per million cubic feet of gas should be applied until all leaks have been stopped; then the amount should be increased to and maintained at approximately 50 pounds per million cubic feet of gas.

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EXPLOSION IN THE POST-OFFICE BUILDING, GLENDIVE, MONT.

On February 12, 1936, at 8:10 a.m., a violent gas explosion occurred in the new post-office building in Glendive, Mont. Eleven persons were in the building at the time of the explosion, three of whom received minor injuries owing largely to flying or falling material, and two were severely burned.

Natural gas in which no malodorant was used at the time of the explosion is supplied to Glendive from the Cedar Creek anticline, about 40 miles to the south.

The building is a one-story brick structure with full basement, the concrete floor of which is laid directly on the ground with no subfloor chambers. To prevent seepage of water underneath the foundation walls and basement floor exterior and interior subdrainage systems are provided.

These drainage systems discharge into a catch basin, thence into a sump, both being in the building below the level of the basement floor. From the sump the water is pumped into the storm sewer, which is at a higher elevation than the sump.

A 2-inch gas main carrying 30 pounds pressure per square inch was buried 2 feet below the surface of a concrete street pavement, 37 feet from and parallel to the post-office building. Owing to the extremely cold weather that prevailed for a month before the explosion this gas main contracted and pulled apart at a point opposite the building. Although the ground in which this pipe was buried was frozen solid the gas traveled laterally 37 feet and downward 8 feet, where it entered the exterior and interior subdrainage systems.

Once in these systems, the gas found its way easily into the catch basin into which these drainage pipes discharged. The catch basin and sump are in a room directly beneath the postmaster's office. This room became filled with gas from the catch basin through a pipe sleeve that carried a steam line to a radiator in the postmaster's office above.

The evidence indicated quite definitely that the source of ignition was a lighted match and that the explosion originated in the postmaster's office.

Because of the intense heat developed in this office and the damage wrought in the building, there is every reason to believe that the accumulation of natural gas was around 9 or 10 percent - the most violent or dangerous explosive mixture of natural gas and air.

To determine whether sewer gas was the explosive agent samples were taken from the subdrainage systems after the explosion and analysis revealed the same constituents as those of the gas supplied to Glendive, samples of which also were analyzed.

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The only gas line in this building was a 2-inch low-pressure (6-ounce) line that projected about 1 inch through the rear wall of the boiler room and had no branch lines. This pipe was capped securely to prevent leakage.

The idea is fairly prevalent that if combustible gas is not piped directly into a building - that is, if a building is not serviced - it is more or less immune from gas explosions. This is definitely erroneous. Should a leak develop in a building that is serviced the presence of gas may be detected easily by the sense of smell if a malodorant has been introduced into the gas. On the other hand, should the leak develop outside the building, with consequent lateral migration of the gas into the basement or other chambers, its presence may not be detected by the sense of smell because the action of the ground probably has destroyed the effectiveness of the malodorant.

Conclusions Regarding Glendive Post-Office Explosion

The following conclusions in connection with the explosion at the Glendive post office are based upon both direct and circumstantial evidence obtained by the investigators from eyewitnesses and a thorough and comprehensive study of conditions in and around the post office following the explosion. It is believed, therefore, that the evidence presented in this report is conclusive beyond a reasonable doubt.

1. The explosion originated in the postmaster's office.

2. Natural gas (largely methane) entered the building from a nearby broken gas main via the exterior subdrainage system and perhaps to a smaller extent through the medium of the interior subdrainage system, both discharging into the catch basin connected with the sump in room 3. The gas then passed through the pipe sleeve, carrying a radiator steam line, into the postmaster's office above.

The ascending current of warm air from the radiator carried the gas to the ceiling of the postmaster's office and, being lighter than air, accumulated next to the ceiling; as it continued to enter the office the layer of gas next to the ceiling became thicker until much if not most of the room from ceiling to floor was filled with an explosive mixture.

3. The explosive mixture was ignited by the flame of a match.

4. There was only one explosion, the flame of which was confined principally to the postmaster's office but extended about 15 feet into the lobby and into the workroom across from the finance section.

The question naturally arises as to why the flame from the explosion did not descend through the pipe sleeve, through which the gas ascended into the postmaster's office, and cause an explosion in room 3. The reason very probably is that the pressure developed by the explosion pressed the floor plate tightly against the floor; this, or possibly the fact that the

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floor plate, pipe sleeve (which is about 6 inches long), the floor, and the steam line cooled the flame and quenched it before it had time to pass downward through the pipe sleeve into room No. 3.

5. From the standpoint of safety it is poor practice to terminate the discharges of unobstructed, open, unvented subdrainage systems within the confines of a building.

6. In view of the numerous broken gas mains throughout the country during the very severe winter of 1935-36, obviously such mains either should be laid below the frost line or should be provided with suitable expansion joints.

Recommendations in Glendive Case

1. The subdrainage pipes, which discharge into the catch basin and the sump, should be extended downward to within a few inches of the bottom of the catch basin and the sump so that a water seal always may be maintained over the ends of the pipes.

2. Similarly, the opening in the wall between the catch basin and the sump should be provided with pipes extending downward on each side of the partition wall below a definitely maintained water level, so that their ends will be water-sealed at all times.

3. An automatic signal should be installed to operate when the water in both catch basin and sump drops to a dangerously low level, and it should be some one person's specific duty to see that the proper water level is maintained.

4. The catch basin in the Glendive post office should be vented by a 4-inch pipe extending through the roof and having an airtight manhole cover provided with a gasket and bolted securely in place.

5. In the construction of future Government buildings requiring subdrainage systems similar to those of the Glendive post office the catch basin and sump should be in a properly constructed concrete vault entirely outside the building.

The ideal arrangement would be to have the subdrainage systems discharge directly into a storm sewer without entering the building at all. The elevation of the storm sewer was adverse to such an arrangement at the Glendive post office, hence the necessity for the pump.

6. To prevent blocking during extremely cold weather all vent pipes extending through the roof should be inspected regularly for accumulations of frost or ice.

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EXPLOSION BENEATH POST-OFFICE BUILDING STEPS, SPOKANE, WASH.

On January 13, 1937, about 12:30 p.m., a gas explosion occurred beneath the granite steps leading to the main south entrance of the Spokane post-office building, rather severely wrecking them. Three persons were injured - two slightly and one seriously. Fortunately, the steps and sidewalk in front of the building, normally crowded during the noon hour, were almost deserted at the time of the explosion.

This building was completed and occupied in 1909. It is substantially built, with a concrete foundation on which are superimposed large, dressed, granite blocks up to the level of the first floor, limestone having been used for the building proper. A full basement is provided, with no subfloor chambers.

Over all the steps were about 55 feet in length and, including the landings, were approximately 10 feet in width. They were constructed of granite slabs 5-3/4 inches thick, 16 inches wide, and approximately 7 feet long, each weighing about 760 pounds. Each step rested on the step below and projected over the lower step 3 inches, giving a uniform tread of 13 inches, the vertical height or riser of course being the thickness of the slabs.

The steps were divided into three sections by two large granite blocks extending horizontally and at right angles to the building. At each end of the steps the arrangement was similar. The four large granite blocks supported the four lamp standards. Smaller granite blocks supported the large blocks, which, in turn, rested upon brick walls.

Underneath the blocks supporting the lamp standards were longitudinal channels in the brick walls to carry the conduits to the lights. In these conduit channels also were 1/2-inch gas pipes extending from a point directly underneath the lamp standards through the south wall of the building, into the basement.

Evidently gas had never been turned into these pipes, as the lamp standards were provided with electric-light fixtures only.

The entire step structure was supported by seven concrete beams 13 inches wide, 44 inches deep, and about 9 feet 5 inches long. These beams extend into the south wall of the building, with the other end resting on concrete piers set in the earth. The south end of these beams terminates in a rubble wall bounding the south side of the space beneath the steps.

Brick walls are laid on the concrete beams and the steps and landing slabs rest directly upon them.

The brick walls carrying the two center lamp standards are stepped outward to provide the proper width for supporting the large granite blocks carrying these two lamp standards.

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There were six cavities or unventilated chambers beneath the steps. Five of them were 7 feet wide, 9 feet 5 inches long from north to south, and averaged 6 feet in depth. The sixth chamber, at the east end of the steps, was filled with earth to within about 3 feet of the bottom of the landing slab before the original construction of the steps. The total unventilated air space in the six compartments beneath the steps was approximately 2,100 cubic feet.

In the next compartment to the west a 4-inch low-pressure gas-service line enclosed in a two-section 6-inch pipe sleeve passes through this compartment or chamber from south to north and thence through the south basement wall and projects about 2 feet into the basement, where it is closed tightly with a valve. Inby this valve the 4-inch line is reduced to 1-1/2-inch and then to 1/2-inch lines. There was no leakage from these gas lines in the basement, and gas had not been used in the building for several years.

The gas, which is manufactured and distributed to the city of Spokane by the Spokane Gas & Fuel Co., is a mixture of carbureted water gas, coal gas, and a small amount of oil-refinery gas. The mixture is composed of about 1 part water gas to 3 parts coal gas. It has a strong, disagreeable odor, is highly explosive when mixed with air, and has wide limits of explosibility, ranging from 6 to 36 percent.

In addition to its explosive qualities this gas also is deadly when breathed because of the high carbon monoxide content (10 percent, approximate average), 0.5 percent of which is likely to produce unconsciousness and death in a very few minutes.

Because of the strong, disagreeable, characteristic odor of this gas warning agents or malodorants are unnecessary and are not introduced into it. Upon the basis of odor intensity this gas, as detected by the sense of smell in the basement of the post-office building before the explosion, would, it is believed, rank fourth in the scale and would be described as "strong."[4/]

On January 12, the day before the explosion, the presence of gas was detected by its disagreeable odor in the basement of the post-office building. Furthermore, on this day the presence of gas was similarly detected in the basement of a store situated on the southeast corner of the block immediately east of the post-office building, some 300 feet away on a straight line from the point of break in the gas main in Lincoln Street.

The assistant custodian of the post-office building reported the matter to the gas company immediately. A crew of men went to work forthwith to find the leak or leaks. After considerable drilling through the pavement, the leak was discovered 12 feet north of the telephone company manhole near the northeast corner of the post-office building. Although it is alleged that the leak was found on January 12 final repairs were not completed until 4 p.m., January 13, or about 3 hours and 30 minutes after the explosion. The repairs were made by applying a Dresser coupling to the broken pipe ends.

4/ Fieldner, A.C., Sayers, R. R., Yant, W. P., Katz, S. H., Shohan, J. B., and Leitch, R. D., Warning Agents for Fuel Gases: Bureau of Mines Monograph 4, 1931, p. 58.

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Gas was smelled in the pump room at 2 a.m., January 13, by at least two persons. This is significant because the pump room is separated from the reservoir beneath the steps by the south basement wall only. Owing to the situation of the pump room with respect to the points of entry into the basement of the 6-inch steam line and telephone cable it is evident that the leakage of gas into the pump room came through the south basement wall and not through the east wall.

Furthermore, the door of the pump room usually is kept closed, and there are several doors and intervening passages between the pump room and the rooms into which the steam line and telephone cable enter.

Lincoln Street rises on a 3-percent grade from north to south where it parallels the post-office building. The gas, being lighter than air, would tend to flow through the gravel formation and also follow any available openings surrounding pipe lines, sewers, etc., in an effort to escape. In this manner the gas found its way into the cavity beneath the steps.

Just when the break in the gas main occurred is unknown. It may have been several hours or several days from the time the break occurred to the time the odor of gas was first noticed in the basement of the post-office building.

The theory that a bomb or other high explosive had been placed beneath the steps and detonated is untenable because there were no openings or vents connecting the space beneath the steps with the outside atmosphere, other than such openings or cracks as may have developed where the mortar or "pointing" had worked out of the joints of the steps as a result of possible expansion and contraction or frost action. It is believed that in this case such openings would not exceed 1/8 inch. Obviously, therefore, it would have been impossible to place high explosives beneath the steps without first providing an opening.

The pressures developed by the explosion, as evidenced by the damage, were fairly uniform in all of the compartments except that at the east end of the steps. This compartment showed less violence because its cubical content was much less than that of the other five compartments.

The uniformity with which the steps were blown both upward and outward toward the street is typical of the action of a gas explosion.

Although most of the steps were broken and one or two of the landing slabs were sheared to some extent there was no evidence of shattering, as unquestionably would have been the case with high explosives.

In view of the foregoing it can be stated confidently that the explosive agent was manufactured gas.

The igniting agent is unknown. The most plausible theory is that a lighted match was thrown on the steps near a small opening or crevice between

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the steps, through which the explosive mixture was issuing. It is well-authenticated that during the lifetime of the building it has been necessary at times to point, or fill in with cement mortar, the joints of the steps.

As there are no trolley cars in the city and no nearby electrical installations of magnitude, ignition from stray currents would appear unlikely. Furthermore, sparks from hobnails or exposed tacks in the shoe heels of pedestrians, caused by contact with the granite steps, would appear equally improbable, and sparks from a static charge as a medium of ignition is difficult of conception.

Testimony of several employees in the building indicates that the explosion underneath the steps was preceded by an explosion of much less intensity in or near the open manhole at the northeast corner of the building, the interval between the two explosions having been 2 or 3 seconds; this explosion did no damage, and those who heard it were convinced that it was not the back-fire of an automobile.

The theory was advanced that the flame from the initial explosion ignited the gas beneath the steps, causing the second explosion. That the short interval (2 or 3 seconds) between the two explosions was a mere coincidence is borne out by the fact that it would have been a physical impossibility for the flame from the first explosion to have traveled some 200 feet through a gravel formation or along possible openings surrounding gas and water lines to reach the point of the second explosion.

It is understood that at the time of the first explosion employees of the gas company were working near the break in the 4-inch gas main, which occurred 12 feet north of the manhole. It is rather singular that no one was burned or otherwise injured as a result of the initial explosion.

During the early stages of the investigation it was believed that an accumulation of gas in the pump room had been ignited by a spark or arc from one of the pump motors, resulting in an inflammation rather than an explosion, and that the flame passed through the space surrounding the 4-inch gas line entering the pump room, thereby igniting the main body of gas beneath the steps.

Although some of the jute packing surrounding the 4-inch pipe was blown into the pump room, subsequent inspections led to the conclusion that the packing perhaps was tight enough around this pipe to prevent propagation of flame from the pump room, through the basement wall, into the reservoir beneath the steps.

Another theory as to the possible source of ignition was that a short-circuit occurred in the wiring leading to the lights on the four lamp standards. It was not difficult to conceive that the spaces immediately beneath the large granite blocks supporting the lamp standards had become filled with gas by leakage through the not very tightly constructed brick walls supporting the large granite blocks. This theory was discarded, however, when the assistant custodian stated that current had not been turned into these lamp circuits for a year or more.

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Conclusions Regarding Spokane Post-Office Explosion

In view of the facts ascertained in connection with the investigation of this explosion, the following conclusions appear to be logical, reasonable, and well-founded:

1. The explosion was caused by ignition of a body of gas beneath the steps of the post-office building.

2. The gas involved in the explosion was manufactured.

3. The accumulation of gas beneath the steps of the post-office building was due to a break in a 4-inch low-pressure gas main in Lincoln Street near the northeast corner of the building and outside the post office.

4. The type of gas escaping from the break in the 4-inch low-pressure main was positively identified by its characteristically disagreeable odor in the basement of the post-office building and elsewhere by several postal employees.

5. The break in the 4-inch gas main was due to contraction of the metal pipe as a result of subzero weather.

6. Unfortunately, the igniting agent could not be determined definitely. The most plausible theory regarding the source of ignition was that a burning match, cigar, or cigarette was dropped on the steps near a small opening in the step joints, from which an explosive mixture was issuing.

7. That there were two explosions appears to be well-established. The first was of much less intensity than the second, and no damage is known to have resulted therefrom.

8. Although the interval between the two explosions was said to be only 2 or 3 seconds it is believed that the time element was a mere coincidence.

9. The initial explosion did not ignite the second; there was no relationship between the two explosions other than the fact that they were both gas explosions.

10. It is believed that the explosion originated near the center of the steps.

11. Manufactured illuminating gas does not lose its malodorant characteristics after migrating through the ground, even for a distance as great as 300 feet.

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Recommendations in Spokane Case

To the end that future similar occurrences may be avoided in Spokane and elsewhere, the following recommendations were offered:

1. The open spaces beneath the front steps of this building should be filled completely with earth or other suitable material before the steps are restored.

2. The material used for filling these spaces should be tamped thoroughly during the process of filling to prevent shrinking.

3. The 4-inch gas line entering the pump room through the south wall of the building should be disconnected from the 6-inch main on Riverside Avenue and removed. If this is not done, the small gas lines beneath the large granite blocks supporting the lamp standards should be removed and the connections capped tightly.

4. If the 4-inch gas line entering the basement is removed the aperture left in the wall should be filled completely and solidly for its entire length.

5. All openings in the basement walls of the building below ground level through which pipes, conduits, cables, etc., enter the building should be sealed tightly enough to prevent gas from entering the building.

6. The assistant custodian should designate some one person to inspect such seals regularly. These seals should be inspected just before the beginning of cold weather and more frequently during the winter. The expansion and contraction of pipes and conduits will tend to loosen and possibly dislodge the sealing material.

EXPLOSION IN OHIO STATE OFFICE BUILDING, COLUMBUS, OHIO

An explosive mixture of natural gas and air that had accumulated in the subbasement of the new Ohio State office building at Columbus was probably accidentally ignited by a match about 2:42 p.m., April 14, 1932. Ten men were killed and 50 injured; property damage was estimated at $500,000 to $1,000,000. Apparently gas from a broken main close to the building found its way into the subbasement. As is usual, even with modern structures, the basement was not and probably would not be ventilated unless some unusual local condition should require ventilation.

At the time of the disaster the building was about 99 percent complete. It had 14 stories above the main floor. Below the main floor was the ground floor, and below it, under the main building, was the basement. Below part of the ground floor were two excavated and enclosed spaces, which were not back-filled; one space communicated with an otherwise enclosed space below the basement of the main building. It was unventilated and completely enclosed except for certain holes around pipes passing through the walls.

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A 24-inch manhole provided with a cover through the basement floor gave access to the space. A 16-inch gas main had been laid 3 to 4 feet below the sidewalk near the building, and a 57-inch sewer ran under the center of the building.

Immediately before the explosion, 126 persons were in and about the building and 20 city workmen were grading a drive close to it. About 1-1/2 hours before the explosion two bronze workers had cut holes through the concrete floor to the enclosed space. Then they started to cut holes at another place. Meanwhile a foreman had inspected these holes and a carpenter was placing a form under each hole. One of the bronze workers was called there for some purpose. The explosion then took place at the first holes and killed one bronze worker, the foreman, and the carpenter. It is believed that one of the men at the hole, perhaps after lifting the manhole cover nearby, struck a match and thus ignited gas.

After the explosion gas was burning at a curb drain and other places on the nearby drive where city workmen were injured. The top of the sub-basement level and the top of the enclosed space on the ground-floor level were blown off. A large steam line above the subbasement was broken, walls were cracked and moved, elevator shafts were badly damaged, and many windows were blown out; however, the main structural beams in general were undamaged. One of the high-tension (8,000 volts) wires above the curb drain was severed and gave off arcs and sparks as it struck the ground.

Several weeks before the explosion a break was discovered in the gas line under the sidewalk near the building. After the disaster the gas company stated that there was a break near the curb drain but contended that a block of marble displaced by the explosion had made this break. It was not determined whether there was a direct path for the natural gas from the break in the pipe under the sidewalk to the unexcavated area near the hole in the walls below the ground floor. The enclosed space had not been entered since January 1932, so it easily could have been filled with gas had any seeped into any part of the space below the ground floor and vicinity. Samples of air taken in the space after the explosion did not reveal any gas. There was evidence of an explosion in the sewer below the building.

During litigation following the explosion the gas company contended that before any natural gas was brought to Columbus, gas was ignited frequently around a watering trough that stood on the site of the office building.

Recommendations in Ohio State Office Building Case

1. Natural-gas mains should not be placed under sidewalks, close to buildings.

2. Medium- and high-pressure gas mains, particularly, should be so welded, coupled, and installed that they will not leak.

3. Wherever possible, buildings should be so designed as not to have closed, unventilated, underground spaces.

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4. Floor and walls of buildings with closed or open underground spaces should be made as nearly gastight as possible. Pipes running across such spaces should be enclosed in concrete tunnels or sealed tightly where they pass through the walls.

5. Spaces in buildings below the ground level should be ventilated adequately, preferably by mechanical means.

6. During construction dark spaces should be illuminated with hand flashlights only, preferably of permissible types, and smoking should be prohibited.

7. Sewers should not lie directly under buildings but preferably under streets or other spaces not occupied by buildings; this would not apply if the sewer is in a tunnel with 50 or more feet of solid strata above the sewer.

TWO GAS EXPLOSIONS, MUNHALL, PA., DECEMBER 5 AND 6, 1929

A gas explosion occurred about 12:40 p.m., December 5, 1929, in the post-office building at Munhall, Pa., on the outskirts of Pittsburgh, Pa. Six lives were lost, and more than 40 persons were injured; the two-story building (22 feet wide and 40 feet long) was completely demolished.

The building was on a foundation that left an excavation of nearly 3 feet under the first floor. The gas main in the street in front of the post office had leaked before, but a rubber patch had been clamped in place. It is presumed that this patch leaked and that the gas followed along the pipe line into the cellar excavation. Presumably the open flame of a gas stove ignited the explosive mixture of gas and air. The full force of the explosion struck a passing trolley car, derailing it and injuring several persons.

The following morning the proprietor of a drug store about 50 feet from the post office detected gas fumes and called three plumbers to investigate. As one of the men started to descend to the basement, he turned on the electric-light switch, then saw a spark, followed immediately by an explosion. He and seven others were injured by the blast.

After the explosion, gas was seen to be burning at about 25 places on the street, indicating that the explosion had been caused by gas leaking from a gas main. The gas mains were shut off, and the entire district was without gas for several days until adequate repairs could be made.

The post office had been moved during widening of the street several years before the disaster and, owing to the contour of the ground, was placed on low foundation walls. Like many other public buildings, it had the common defect of an unventilated area under the main floor. Entrance of gas lines, which supplied the fuel for heating the post office, was through the walls and an opening large enough to allow gas from the leaking

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main to enter the unventilated space. The gas also traveled 50 or more feet and leaked along the gas line into the drug store. Gas burning at many points along the curb indicated its source.

Recommendations were not made by Bureau engineers, but naturally they would have followed closely recommendations made at other disasters discussed in this publication.

EXPLOSIONS IN DWELLINGS AND BUILDINGS

Almost daily newspapers throughout the United States report gas explosions in buildings. Apparently they occur with monotonous regularity, but ordinarily too few persons are injured to attract much attention - only disastrous explosions are given more than passing notice. Many of the smaller gas ignitions should have served as warning of the possibility of more disastrous occurrences, but usually the warning has gone unheeded. The number of deaths and the combined property damage of all the small explosions, if assembled as one occurrence, would constitute a catastrophe of very serious proportions.

A few examples of these accidents and the manner of reporting them follow.

An explosion wrecked a new $300,000 Methodist church in Montgomery, Ala., November 29, 1932, killing one workman and injuring another critically. Construction officials said the man who was killed entered the boiler room and struck a match, which ignited gas escaping into the room. Scores of workmen had left the building for lunch a few minutes before the explosion sent the walls crashing to the ground.

Three persons in a Kroger market in Pittsburgh, Pa., escaped without injury on December 13, 1932, when accumulated gas under the sidewalk exploded and wrecked the store. A broken gas main had allowed the gas to escape.

A gas explosion wrecked the front of a bakery in Pittsburgh, Pa., on September 29, 1932, seriously injuring the baker when he struck a match to light the oven. Investigators said that gas had leaked into the chamber.

A baker was injured slightly and two plate-glass windows were broken when a gas leak allowed gas to accumulate in a bakery in Mount Lebanon, Pa., July 1, 1937. The explosion occurred when the baker struck a match to light the ovens in the basement.

Five men were killed and four men and three women seriously injured in a gas explosion that ripped out the walls of the Times Spring Co. in Elyria, Ohio, November 9, 1929. According to the Associated Press a flaming column of gas spurted more than 100 feet into the air, and the walls of the plant "crumbled like paper" when a workman entered a gas-filled room in the building and struck a match to light a cigarette. A foreman smelled gas as soon as he stepped into a room; he noticed a man taking a cigarette from a

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pack, and called to him not to strike a match, but he was too late with his warning and the explosion followed as soon as the match was lighted.

One man was killed and 33 suffered from lacerations, bruises, and burns in the fire that followed an explosion of gas that ripped open a one-story plumbing shop and wrecked several other stores in Detroit, Mich., April 25, 1932. The accumulation of gas was discovered by the crew of a truck while dumping coal into the basement of the shop. Fire-department officials were summoned, but the explosion occurred before the stores and apartments could be vacated. According to police, a defective gas main was broken by the coal-truck crew when they emptied coal into the basement; the escaping gas was ignited by fire in a furnace.

The Pottsville (Pa.) Journal reported the following:

> New York, August 8, 1934. - A gas explosion that sent a ton of brick and mortar tumbling to the street damaged four penthouses on the roof of an 18-story apartment building in Greenwich Village today.
>
> One woman was so badly injured police at first believed her dead. An emergency squad was summoned, however, when a spark of life was detected, and oxygen was applied amid the ruins of the expensive roof-top apartments****.
>
> Police said that the dying woman was Jeanette Baer, renting agent for the huge building, which houses 125 families. They formed a tentative theory that she had smelled gas leaking in one of the penthouses and had gone to investigate. Possibly she had lighted a match.

An accumulation of gas exploded October 18, 1932, in the cellar of a house at Tacony, a Philadelphia suburb, seriously injuring three men, two of whom were employees of the Philadelphia Gas Works Co. The three men entered the cellar in search of a gas-pipe leak and had reached the foot of the cellar steps when the gas, which had accumulated from a leak in a supply pipe leading from the street, exploded with a terrific roar that shook the neighborhood.

Gov. William G. Conley received burns of the face and hands on November 28, 1932, when gas exploded in the basement of the executive mansion in Charleston, W. Va. The governor had gone to the basement to adjust the furnace. He was thrown 40 feet.

An explosion and fire destroyed a four-room bungalow in Monessen, Pa., on December 18, 1932. The blast was attributed to escaping gas.

A terrific gas explosion injured five persons and nearly demolished a three-story multiple building near Etna, Pa., on December 21, 1932.

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The cause was a match struck by one of the injured men while looking for leaking gas in the basement. The escaping gas was believed to have come from a vacant house next door, as the greatest damage was done in that house.

A mother and her 8-year-old daughter died in an explosion of gas in Pittsburgh, Pa., July 25, 1933; four other children were uninjured. The woman, who had retired for the night, smelled gas and lighted a candle and, accompanied by her daughter, began to investigate; when she reached the attic, the blast occurred, setting fire to the clothing of both mother and daughter.

It was alleged that gas leaked into a cellar from a defective line in Pittsburgh, Pa., December 28, 1933, and when a door was opened the fumes came in contact with fire in a stove. The resulting explosion injured a woman so severely that she died 2 days later.

A 75-year-old woman narrowly escaped serious injury when a gas explosion in her Pittsburgh (Pa.) home on February 10, 1933, broke doors and dishes and shattered windows. The explosion occurred in the bathroom.

A Pittsburgh (Pa.) man decided to end his life on Christmas, 1934. He turned on a gas jet in the bathroom of his home and lay down to wait for death. After a few minutes he became nervous and decided to smoke a cigarette while waiting for the gas to take effect. He walked into an adjoining room, lighted a cigarette, and re-entered the bathroom. Just as he was settling himself on the floor again the gas exploded, ripping out sections of the house walls and tossing the man through the door. He was taken to a hospital in a serious condition.

A gas explosion in a New York City apartment demolished two apartments and broke "several hundred" windows. A man turned on four gas jets in the kitchen range and committed suicide. The escaping gas was ignited by a spark from an electric refrigerator motor.

Seven girls were burned in an explosion in a cottage at Ruggles Beach, Ohio, on June 20, 1937. As the girls sat down to breakfast there was a minor explosion in the hot-water heater in the basement, and the basement then filled with fumes. An employee of Ruggles Beach opened the basement door to descend and relight the heater. A moment later there was another explosion, and flames came up a stairway into the dining room. Presumably when the door was opened the fumes came in contact with the stove or were ignited by a match when the employee attempted to light the gas heater.

Three men were injured, one seriously, when an explosion "ripped" through a cellar of a Pittsburgh (Pa.) home on February 19, 1931. The men were in the basement of the home charging a battery, which may have had a defective wire, when the blast occurred. They attempted to extinguish the flames and were burned painfully.

A similar explosion had occurred in the same place February 8, 1931, when one of the men injured in the second explosion lighted a cigarette in the cellar. It was believed gas was responsible for both explosions; no report had been made of the first explosion.

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In most of the examples given, gas leaking from gas mains or defective appliances was ignited by matches or by fires in stoves or gas heaters. If the general recommendations given in this publication are followed, most accidents of this type will be avoided.

NEW LONDON (TEX.) DISASTER

On March 18, 1937, at about 3:05 p.m., a disastrous explosion occurred in the main building - the largest of 11 - of the New London (Tex.) school center, causing the death of 294 persons - 280 pupils and 14 teachers.

The school is in Rusk County, in the south-central part of the great East Texas oil field, about 3.5 miles southeast of Overton (the nearest town of importance). It is a rural school attended by children from a radius of 15 to 20 miles. All grades from the kindergarten through high school attended, with a total enrollment of about 1,250. The main building, in which the explosion occurred, was used for classrooms for pupils in the higher elementary grades and high school only.

As the details of this disaster have been covered fully in a previous publication of this Bureau5/ only the following brief summary is included here:

Construction

The floor plan of the building was in the form of an "E", with the vertical part of the letter forming the front of the building and facing west. Construction on this part of the building, which was one story in height, was begun in the fall of 1932, and classes were held in it early in 1933. Approximately 2 years later two-story additions transverse to the line of the wings were added to the north and south wings. The length of the building from north to south was 254 feet.

The building was supported by a reinforced-concrete foundation wall about 12 inches thick, with the first floor of concrete resting on concrete beams supported by concrete piers 12 inches square, which in turn rested upon concrete footings 12 inches thick and 46 inches square placed 3 or more feet below the ground surface. The foundation walls and the concrete floor were poured as a unit. Wooden supports or sills 2 inches square were spaced at regular intervals upon the concrete floor, to which was nailed a diagonal subfloor of pine. A hardwood floor was laid on top of the subfloor.

The walls of the building were of brick, standard size, backed by 8- by 8- by 12-inch 8-cell hollow tile. The roof was of flat tile laid upon wooden sheathing supported on steel trusses and wooden purlins and rafters. Window sashes of steel were set in steel frames.

The concrete floor of the main building was 3 to 5 feet above the ground. This, with the four walls, formed an enclosed space or subfloor chamber, with a volume of about 46,000 cubic feet. Access to this space was by two doors 4 feet square in the rear wall near the north and south ends, respectively.

5/ Parker, D. J., Jones, G.W., Hill, H.B., and Wade, Gustav, Explosion in School Building at New London, Tex., March 18, 1937: Bureau of Mines Report of Investigations 3365, 1937, 29 pp.

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There were also four small 11- by 22-inch openings or ventilators through the foundation wall, two in the rear and one each in the north and south walls. Whether these four openings were glassed in or only closed with screen wire could not be determined definitely. The door at the north end connecting the manual-training room on the ground floor of the two-story extension of the north wing to the subfloor chamber was said to have been left open as a rule because some of the lumber used in the manual-training room was stored just inside this door beneath the main floor.

The location, number, and size of the openings (assuming that the ventilators were open at all times and including the two doors into the subfloor chamber) did not allow enough ventilation to prevent an accumulation of standing gas in the chamber.

Heating System

The building was designed to have a central heating plant, but to reduce cost of operation and maintenance the plans were changed to include individual heating units using natural gas.

The school was heated by 72 gas steam radiators individually operated in the several rooms and halls. The radiators, varying in size to suit particular needs, were of a type approved by the American Gas Association Laboratories at Cleveland, Ohio. Care and operation of the radiators were under the direction of a janitor, who lighted the gas radiators in the mornings before school opened and used his own judgment as to the number required to give proper room temperatures. Instructions on the approval plate of the radiators stated:

> To light gas, turn gas cock on full and at the same time apply a lighted match through the opening marked "Light Here." The automatic regulator lowers the gas flame when the proper steam pressure is reached, and to fill chamber, remove cap from filling cup when RADIATOR IS COLD and pour in slowly as much water as possible, then replace cap tightly. Refill when necessary.

The heaters were equipped with thermoregulators, which operated on the radiator-temperature rather than steam-pressure principle. As the radiator approaches the desired temperature the thermoregulator cuts down the gas supply, but not enough to extinguish the flame. The flame acts as a pilot and thus prevents unburned gas from escaping through the radiator and into the flue. If the flame is extinguished while the radiator is turned on gas will continue to flow through the radiator and out into the flue or room until the main gas cock is shut off. It is evident that with this particular type of radiator it is possible for unburned gas to be discharged from the heater if the flame is blown out.

Inspection of the vents from radiators in the rooms that were not damaged badly disclosed that some of the radiators were not vented properly, the vents having been merely led into the hollow-tile walls; others were not provided with vents where they were not accessible.

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The radiators were not fastened to the floor and could be moved about with little effort. Such movement may have caused the connections to break below the floor and caused the gas to leak into the chamber; no definite evidence was obtained to support this theory as to the cause of the gas leakage, though some credence was given to it by some investigators. A janitor stated that the radiators sometimes were moved a short distance during cleaning.

There was considerable discrepancy in reports as to the number of radiators that were in operation at the time of the explosion. The weather was warm, and records at a nearby airport showed a temperature of 71°F. at 3:00 p.m. The janitor who lighted the radiators on the morning of the explosion stated that only seven radiators were in operation, five of which were in the halls and two in rooms that were not greatly damaged by the explosion; on the basis of this information, radiators were not in operation in any of the rooms directly over the unventilated chamber in which the explosion originated.

Gas Supply

Natural gas was supplied to the school by a public service company until about January 18 through its own line and meter setting, after which connection was made with a residue-gas line of a nearby producer of gasoline. The gas from the public-service company was not used after January 18, but the pressure regulators and connections were left intact so that service could be resumed if the gas supply from the nearby gasoline company were shut off.

The East Texas oil field presents a peculiar situation, not appreciated or understood in many other sections of the country, relative to the disposal of residue gas. The primary endeavors in this oil field where the school is situated are the production and marketing of oil. When the oil leaving the wells at high pressure reaches the surface the pressure is lowered, and varying amounts of residue gas initially dissolved in the oil are liberated. The liberated gas contains appreciable amounts of heavy hydrocarbons and gasoline, and where the amount present in the gas is large enough to be recovered the heavy hydrocarbons are removed; this was the situation at New London. The gasoline company from which the New London school procured its gas has a modern plant for the recovery of butane and gasoline from waste gases in the district. The so-called "wet" gas is gathered in lines and taken to the plant, where the salable products are recovered. The gas is then sent back through pipes alongside the collecting lines to the leases from which the gas originally came, to be used as fuel in boilers or for other purposes.

It is more or less general practice for persons, schools, and churches near these lines to make connections and use the gas free of charge, because any excess gas not used for heating and power purposes is burned in open flares.

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Sometime in February the gasoline company began to recover butane from the gas, which it had not done before that time; therefore, the gas used at the time of the explosion was "drier" than at the time the connection was made in January.

The residue-gas line of the gasoline company passed several hundred yards south of the school building in an east-west direction. Janitors at the school laid a 2-inch line from the school building to the 4-inch gas line and made connection therewith. Whether the school was given permission to use the gas without charge is irrelevant to the cause of the explosion. The significance of the change from dry gas supplied by the United Gas Co. to gas from the gasoline company is whether there was a marked change in the density, heating value, and pressure at which the gas was supplied to the school, insofar as they offered a greater tendency to cause leaks in the gas mains and service connections in the space under the first floor of the school where the explosion originated, or whether this gas produced greater violence on explosion.

Natural Gas Cause of Explosion

The investigation disclosed definitely that high explosives, sewer gas, or seepage of gas or hydrocarbon vapors from nearby oil wells and pipe lines did not enter into the explosion. The only remaining source of combustibles, therefore, was the natural gas supplied to the building for heating purposes.

The only evidence contradictory to the general conclusion that the explosion was due to an accumulation of highly explosive natural gas-air mixture in the space under the first floor was given by a janitor at the school, who stated that he entered the space through the door at the south end on the morning preceding the explosion and ignited a match to light a cigarette. He observed nothing unusual, and no explosion resulted when the match was ignited.

This evidence merely shows that at one location in the south end of the space under the floor natural gas in explosive proportions was not present; however, it is not at all certain that appreciable percentages of natural gas were not present there also. It must be considered that in the district where the school is situated numerous oil wells and pipe lines are present and the air is permeated with hydrocarbon odors most of the time, hence the odor of natural gas in the space might not have created suspicion. A mixture of natural gas in air below the lower explosive limit will not propagate flame but will cause the flame of a lighted match to elongate.

Explosion

The explosion, heard for 12 miles, completely wrecked the entire building directly over or adjacent to the unventilated chamber under the first floor, as well as parts of the two-story buildings attached to the one-story building and the auditorium. Damage in these parts was caused largely by the movement of large volumes of gases under pressure following paths of

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least resistance to the outside atmosphere. After the explosion parts of the auditorium remained standing but were torn down to prevent accident.

Witnesses interviewed stated that the building actually rose in the air, then crashed down into the unventilated space within the foundation walls. A witness at work across the road west of the school building said the explosion started at the north end of the building and to him looked like a row of dominoes falling down as the explosion passed from the north to the south end. He also stated there was no flame, but that there was considerable white dust followed by reddish dust after the explosion. He said that the explosion lasted for about 1 second and that the noise was like a rumble or roar, which increased in pitch near the end.

To the north of the building bricks and tile were thrown 300 feet from the foundation, and to the south and rear about 500 feet.

Parts of the foundation wall were torn from the ground or, where not torn out, were pushed outward at the top. In one instance a section of the foundation wall estimated at 1,500 pounds was hurled through the air for at least 25 feet and landed in an automobile parked nearby.

Only one small fire occurred at the time or after the explosion, and it was extinguished quickly. An official of an oil company arrived on the scene soon after the explosion, had the gas turned off, and inspected the ground and wreckage to make sure that combustible gas or vapor was not present before permitting those helping with the rescue work to use acetylene torches to cut apart the steel in the wreckage.

Only a few of the victims were singed or burned, and these were at the north end of the building in or adjacent to the manual-training shops. Injuries and deaths were due largely to violence and to crushing caused by the great quantities of concrete, brick, tile, and steel work thrown into the air by the explosion. Limbs and other parts of the body were severed from the victims, and compound and multiple fractures were the usual occurrence, all of which attests to the great violence of the explosion in all parts of the school building along the front and immediately over or adjacent to the unventilated chamber under the first floor.

Conclusions in Connection with New London Disaster

The following conclusions are based upon direct and circumstantial evidence obtained by the Bureau investigators from qualified persons and a thorough and comprehensive study of conditions existing before and after the explosion:

1. The immediate cause of the disaster was ignition and explosion of a large volume of highly explosive natural gas-air mixture that had accumulated in an unventilated space beneath the first floor of the main school building. This space extended along the west front of the building and had a volume of approximately 46,000 cubic feet.

2. The gas was present in the space because of leakage from gas lines and their fittings (possibly a broken service connection) suspended beneath the floor, with virtually no method of detecting the gas or removing it by natural or forced ventilation.

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3. The physical evidence indicates that higher concentrations of natural gas were present in the north section of the space beneath the first floor and suggests that the leakage took place in that part of the sub-chamber.

4. Natural gas did not seep through the soil from adjacent gas lines or wells; this fact was determined fully by evidence obtained from 71 test holes drilled to the rock below the surface formation. Numerous tests for inflammable gas were made of the atmosphere in the holes by means of detectors, and negative results were obtained.

5. Liquid hydrocarbons (crude petroleum and gasoline and their vapors) from surrounding wells and pipe lines were not responsible for the explosion.

6. The source of the gas supply is irrelevant to the cause of the explosion, and the results would have been the same under identical conditions regardless of the composition of the natural gas used. Although the composition of gas supplied to the building at the time of the explosion varied from time to time (a condition that may have caused some trouble in the operation of individual heating units) the pressure on the line was relatively constant and moderate, and no appreciable difficulty should have resulted from the use of the gas. The investigation revealed that the gas line that supplied the gas to the building was provided with traps to eliminate condensate and oily material and thus provide a satisfactory supply of gas for the purpose.

7. Manipulation of an electric switch on a panel in the manual-training room near an open door leading into the north end of the unventilated region under the first floor ignited the gas, and the physical evidence shows that the explosion propagated in a southerly direction through the chamber.

8. Explosive mixtures of natural gas in air from the space under the first floor encompassed the switch panel probably in large part because of a drop in barometric pressure on the afternoon of the explosion and the simultaneous increase in atmospheric temperature. Both pressure and temperature effects, in conjunction with a calm outside atmosphere with very little if any wind velocity, caused the gas in the space to expand. The excess gas was forced from the space through the open door, an opening offering the least resistance. The explosive mixture issuing from this opening either was deflected or was carried to the switch by minor air currents and was ignited by a spark or arc when the switch was manipulated. The flame was carried through the door into the space underneath the floor.

9. The evidence does not indicate that the individual heating units on the first floor of the building ignited the explosive mixture. However, these heating units may have been involved in the formation of the explosive mixtures as they were moved about, and this may have broken a gas connection in the space below the floor.

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10. Tremendous pressures were developed during the explosion, as evidenced by the extent and violence of the destruction, indicating that the natural gas-air mixture was in such proportion as to give the highest rate of flame propagation and pressure development. This large volume (possibly as much as 46,000 cubic feet) of an ignited explosive mixture of gas and air was in an enclosed and substantially confined space, with little or no opportunity for expansion at low pressure. Hence, maximum opportunity was afforded to build up a high pressure as the explosion wave progressed, resulting in widespread disrupting and destructive effect. Evidence of high pressures was the fact that a brick passed entirely through a 12-inch brick-tile wall, a 1,500-pound slab of concrete was thrown about 25 feet into a nearby automobile, and a loose brick was hurled about 500 feet from the foundation.

11. Because the explosive natural gas-air mixture appeared to be uniformly mixed, as evidenced by the violence of the explosion over the entire space under the first floor and the absence of flame and black smoke when the mixture exploded, the conclusion is warranted that the accumulation was due to relatively small leaks rather than to a large leak. In a chamber of the dimensions given and of shallow depth, considerable time must elapse to permit the natural gas to mix uniformly with the air. In view of this fact Bureau of Mines investigators conclude that the gas had been accumulating for some time before the explosion. It is likely that highly explosive mixtures may have been present in the space for some time but did not explode because no source of ignition was present.

12. Obviously it is a grave mistake to allow unfilled or unventilated spaces to remain beneath the floor of any building where combustible gas or vapors may accumulate, either from mains underneath or from seepage through or under the foundation walls from outside sources.

Recommendations in Connection with New London School Disaster

The lessons learned from this explosion warranted the following recommendations, which, if complied with, should in a large measure prevent similar tragedies in future.

1. All schools and other public buildings should be constructed so that there are no unventilated, relatively inaccessible, enclosed spaces or chambers, especially in the basement region, under or near recitation or assembly floors. Wherever possible the first floor should be laid directly on the ground; where this type of construction is impossible spaces between the floor and the ground should be filled with earth or other material, thus making impossible the accumulation of explosive mixtures underneath the floors. Building plans should be studied critically from a safety viewpoint with respect to this architectural feature. Architects can assist greatly in this campaign for future safety in schools and other public as well as private buildings by eliminating underground unventilated chambers, tunnels, or pockets, which become exceedingly dangerous if combustible gases or vapors leak into them and are ignited.

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2. School buildings and other public buildings that have unventilated basements, chambers, tunnels, or other spaces under floors and steps, and attics should be provided at all times with adequate, constant ventilation. Ventilators not only help to keep places free of combustibles but also act as pressure releases if an explosion occurs. If ventilators are of adequate size and are spaced at proper intervals in all sides of a chamber they aid in dissipating the pressure and thus reduce the violence if an explosion takes place.

3. Suitable warning agents with distinct odors introduced into fuel gases that have little or no odor of their own have proved of great assistance in detecting leaks in public buildings and private homes. Although use of malodorants is only one factor to be considered in providing adequate protection (as explosions have occurred with mixtures of air and manufactured gas, which has a distinct odor), fuel-service installations should be studied, especially in school and other buildings where the public assembles, to determine the need for impregnating the gas with an agent that will warn against leakage. The malodorant should be nontoxic, should have a characteristic odor, and should be added to the gas in quantity large enough to give a warning of impending dangerous conditions before explosive concentrations are reached. Even though the teachers and pupils of the New London school were accustomed to odors of gas and oil from the oil field in which they lived it is likely that a malodorant in the gas used at the school would have given enough advance warning to have prevented the explosion.

4. Alarm systems based upon instruments that detect the presence of inflammable gas and bring the existence of dangerous concentrations of combustibles in confined spaces to the attention of officials in charge of school buildings have value but do not solve the problem. Efforts should be made to eliminate the causes, thus making the alarms unnecessary. Highly explosive gas or vapor might accumulate easily in an unventilated chamber or tunnel in so short a time that means could not be taken to eliminate the trouble before the explosion occurred; the elimination of unventilated places where an alarm would be placed appears to be the correct solution.

5. All gas (and electrical) lines serving schools and other public buildings, and all piping, connections, fixtures, appurtenances, and appliances in such buildings should be of permanent construction, placed by competent persons in accordance with the latest approved fire underwriters' or other applicable specifications and operated in accordance with known safe practices; moreover, they should be kept in repair at all times. Where individual heater systems are used the individual heating units should be fastened rigidly to the floor.

6. Responsibility for the construction, maintenance, and operation of gas pipe lines serving the public, and especially for the regulation of pressures in such lines, should be under the exclusive control of persons or organizations experienced in such work. Schools that use gas for heating or other purposes should purchase their fuel supply from a public service company that, through experience and regulation, may be expected to give a

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more uniform supply of gas and thus a better and safer service than can be obtained from a residue gas line not operated to supply the kind of service that is required.

7. Responsibility for the testing, lighting, and general care of the entire heating system should be entrusted only to persons who are familiar with such systems and competent to handle them safely and efficiently.

8. All gas mains to schools and other public buildings should be installed in well-ventilated places, and advantages in safety may be gained by placing gas mains or headers outside buildings, thereby minimizing the hazard of gas leakage in enclosed spaces. In some instances weather conditions, architectural design, or possibilities of aggravated corrosion may make such construction inadvisable. However, a desirable objective is to reduce to a minimum the enclosed piping for fuel purposes within a public building. Some types of construction may require that consideration be given to placing the mains in the attics under the eaves. Under these conditions enough ventilation must be provided to dissipate normal gas leakage through ventilators and under the roof.

9. Although tests proved that the explosion at the New London school was attributable in no way to seepage of gas through the soil experience of investigators of the Bureau of Mines with other gas explosions in surface structures indicates that gas may enter basements and other enclosed spaces that are partly underground. This possible hazard may be present, especially where subsurface conditions permit gas to travel laterally through the soil along pipes that enter the buildings below the ground surface. Accordingly, provision should be made to seal all openings where pipes pass through walls.

10. Central heating systems with the heating plant isolated in a separate structure have definite advantages with respect to protection against fires, explosions, and carbon monoxide. They also have certain advantages in efficiency with respect to large public buildings. It must be considered, however, in planning a heating system, that gas usually is required in some parts of school buildings for cooking, hot-water supply, and chemical and other laboratories, and adequate precautions should be taken in connection with these as well as with heating.

11. A State supervisory body should inspect structures and buildings in which the public assembles and which are outside the corporate limits of cities and towns where municipal safety inspection is in effect. Safety inspection by State or municipal agencies should extend not only to the construction of school and other public buildings but also to plans and design of such buildings and should include structural features as well as details of heating and ventilation.

12. In rural districts where school buildings are not subject to regulated inspection gas companies may be of great service in this campaign of safety through their knowledge of and familiarity with the hazards involved in the use of gas. They should make periodic inspections and offer

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constructive suggestions for the safe use of gas on premises served by them. If these suggestions are not followed gas service to the buildings should be stopped immediately until the proper corrections for safety are made. When mixed with air in certain definite proportions all fuel gases are highly explosive. As the possibilities of forming explosive mixtures are always present - from the initial source of the gas to the point where it is used - extreme care in the utilization of combustible gases is necessary in the interest of complete safety.

INSPECTIONS IN SCHOOLS AND OTHER BUILDINGS OF BUTTE AND GREAT FALLS, MONT.

The appalling loss of life in the New London (Tex.) school explosion aroused grave public concern as to whether conditions similar to those at the Texas school before the explosion might exist in other school buildings in towns using natural or manufactured gas.

Following a request by the Hon. J. J. O'Connell, Montana State congressman, the Director of the Bureau of Mines assigned an engineer to inspect all school buildings in the cities of Butte and Great Falls, both of which use natural gas.

These two cities were selected because five gas explosions had occurred in buildings in Butte between February 1 and June 1, 1937, and one had occurred in Great Falls in 1936. Fortunately, no lives were lost.

The inspection, which began on April 7, 1937, lasted 15 days and included 12 parochial institutions, 21 public schools, 1 business college, 6 Montana School of Mines buildings, and 6 theaters in Butte and vicinity, and 6 parochial institutions and 14 public schools in Great Falls - a total for both cities of 66 buildings.

The object of the inspection was to determine whether there were hazardous conditions, such as unventilated chambers or dead-air spaces, beneath the basement or first floors of these buildings to serve as reservoirs for gas accumulations in the event of gas leakage either within or outside the buildings beneath the surface of the ground. To determine the presence of gas leakage through the ground from nearby mains or from gas lines, meters, regulators, and gas appliances in the buildings, approximately 1,350 readings were taken with combustible-gas detectors of recognized accuracy and dependability. Only one reading revealed the presence of combustible gas.

Thirty-four of the 46 buildings inspected in Butte and 18 of the 20 inspected in Great Falls had unventilated subfloor chambers.

In view of the potential explosion hazards of such conditions, the situation seemed to demand immediate drastic action by those charged with such responsibility.

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Fire-fighting equipment, including fire extinguishers of different types and fire hose, in many instances was substandard in Butte schools, but with few exceptions such equipment was in first-class condition in the Great Falls schools.

Natural gas has very little odor, and its presence may not be detected readily by the sense of smell. It is common practice in many parts of the country to introduce into the gas a chemical with a disagreeable odor to warn of leakage. A malodorant with a characteristically disagreeable odor is used in the gas supplied to Butte and Great Falls. This odorant is apparently highly efficient where a leak occurs inside buildings; however, when a leak occurs outside a building from a buried pipe and the gas migrates laterally through the ground into the basement or subfloor chamber this malodorant is inefficient because it is absorbed, filtered out, or otherwise rendered noneffective by the ground action.

The Bureau of Mines recommends ethyl mercaptan as an effective malodorant for natural gas. An initial concentration of 5 pounds per million cubic feet of gas should be applied until all leaks have been stopped; then the amount should be increased to approximately 50 pounds per million cubic feet.

Because of the definite explosion hazard existing in most of the buildings inspected the necessary remedial action was urged upon those charged with responsibility for safeguarding the lives of both students and teachers.

EXPLOSION IN SCHOOL BUILDING, BARBERTON, OHIO

An explosion of natural gas occurred about 1:30 p.m., May 31, 1939, in an old frame dwelling used temporarily as a school building at Barberton, Ohio. There were 101 pupils, 6 and 7 years old, and 4 adults in the building; 57 suffered more or less severe injuries, but there were no fatalities.

About 2 weeks before the explosion the janitor had detected a gas odor in the basement and he was ordered to shut off the gas at a meter cock inside the basement; the gas company was not notified of the action taken. A leak had developed in a 1 1/4-inch gas line about 3 1/2 feet from the foundation in the ground outside the building; the leaking gas evidently followed the gas pipe, passing through loose earth and the opening in the foundation into the cellar.

The janitor had placed waste paper in the hot-air furnace, had lighted it, and was on the way to the stairs when the flame from the fire ignited the gas. The resulting explosion pushed out the entire lower north and south walls. The east (rear) and west (front) walls and the upper part of the north and south walls remained standing. A brick chimney and stair wall apparently helped sustain the roof and floors, which probably prevented any fatalities.

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The building was old and was to have been razed within a few weeks; hence, it evidently was not in good repair. When the odor of gas was first detected, about 2 weeks before the explosion, a contractor who had exposed the gas line while performing other work had back-filled the trench, but there is no knowledge that this caused or contributed to the break in the pipe. The pipe itself was rusted, and the leak may have been due to weakness of the pipe from rusting.

This explosion again shows the hazard of leaking gas and indicates that at least one safe procedure is to notify the local gas company whenever a leak is suspected. Until leaks have been repaired open lights, fires, and electric current should not be allowed near the suspected source of gas.

LESSONS TO BE LEARNED FROM GAS EXPLOSIONS IN BUILDINGS

A careful study of the gas explosions that have occurred in buildings in the last few years reveals that in many instances unventilated chambers, rooms, or subfloor spaces formed ideal reservoirs for accumulated gas.

Much can be done to prevent these explosions by educating consumers and the public generally to the dangers of gas leakage and proper maintenance of gas appliances, including inspection and supervision.

Obviously it is imperative that immediate research work be done on the problem of developing and using a malodorant that does not lose its effectiveness where gas leakage from street mains migrates laterally through the ground into buildings or other places where it may accumulate.

As long as the practice of burying gas lines beneath street surfaces continues the hazard of leakage from gas lines buried at shallow depth in northern latitudes will continue to be greater during the winter and the explosion hazard accentuated because basements must of necessity be kept closed tightly. If at all possible, gas lines in trenches should be laid below the freezing zone.

Furthermore, the likelihood of gas explosions is increased manyfold where gas lines, meters, and regulators are installed in unventilated subfloor chambers.

Inspection of the schools in two medium-size cities disclosed the alarming fact that a potential gas-explosion hazard existed in most of these buildings because of presence of unventilated subfloor chambers in structures in which gas was used.

The elimination of such hazards will require the wholehearted cooperation of city authorities, school boards, and the gas companies.

Each building presents a separate problem, and whether or not the proper ventilation of subfloor spaces resolves itself into vents to the outside atmosphere, a series of ventilating stacks, or even a separate ventilating

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system of blower fans will require the technical advice of a competent ventilating engineer who has a knowledge of gases, especially explosive gases.

SUMMARY OF RECOMMENDATIONS

1. Natural gas is largely methane, which is virtually odorless, tasteless, colorless, lighter than air, and nontoxic. The explosive range is 4.80 to 15.00 percent in air, the most explosive point being at about 9 percent in air.

2. Manufactured gas is malodorous, lighter than air, and extremely poisonous owing to its high content of carbon monoxide, which averages about 10 percent except when carbureted water gas is employed, when the carbon monoxide content may be as high as 25 percent.

3. Carbon monoxide causes slight symptoms with as little as 0.05 percent, and a concentration of 0.20 percent is definitely dangerous.

4. All natural gas should be treated with a malodorant or stench that retains its disagreeable characteristics after passing through the ground.

5. Ethyl mercaptan is one malodorant recommended to be used in an initial concentration of 5 pounds per million cubic feet of gas until all leaks have been stopped; then the amount should be increased to about 50 pounds per million cubic feet of gas.

6. It is poor practice to terminate discharges of unobstructed, open, and unvented drainage systems within a building.

7. Gas mains should be laid below frost level or be provided with expansion joints, or both.

8. Subdrainage pipes discharging into catch basins or sumps should be extended below the water level to form a water seal at all times.

9. Sumps and catch basins should be vented to the top and outside of the building and, wherever possible, should discharge directly into storm sewers. They should also be in a concrete vault outside of the building.

10. All openings in basement walls below ground level through which pipes, conduits, cables, etc., enter a building should be sealed to keep gas from following them into the building.

11. Gas mains should not be placed under sidewalks or steps but at a greater distance from buildings; they should be so welded, coupled, and installed that they will not leak.

12. Buildings, including steps leading to them, should not have closed underground spaces, but where such spaces exist the floor and walls should

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be made as nearly gastight as possible. Pipes running across such spaces should be enclosed in concrete tunnels or sealed tightly where they pass through walls.

13. Spaces in buildings below ground level should be adequately ventilated, preferably by mechanical means.

14. During construction or inspection as to gas troubles dark spaces should be illuminated by permissible flashlights; smoking and lighting of matches should be prohibited.

15. Sewers should not be directly under buildings unless at least 25 feet of solid strata separate the top of the sewer from the lowest part of the building.

16. Whenever the odor of gas is detected electric switches should not be turned off or on, and matches or other sources of flame should not be allowed near rooms or areas from which the odor emanates.

17. During construction of buildings all lights, fires, and other sources of flame or electric arcs should be prohibited in the basement or similar places where gas is likely to escape from the time workmen start to bring gas lines near or into the building until the work has been completed and the plumber or person directly in charge has approved the installation.

18. In large establishments where men work in basements or other rooms where gas is likely to accumulate tests for gas should be made by a competent employee before workmen are allowed to enter at the beginning of a shift.

19. Gas companies should be notified as soon as leaks or evidence of leaks are discovered; frequently fires and explosions may be prevented by turning the gas off at the curb.

20. Switches to control lights and other electrical equipment in unventilated spaces should be placed outside the enclosures.

21. Schools and other public buildings that have unventilated basements, chambers, tunnels, or other spaces under floors and steps and attics should be provided at all times with adequate constantly functioning ventilation.

22. If a malodorant is not used in the gas supplied by the gas company it should be introduced into the gas when it enters public buildings.

23. Alarms for combustible gas also may be used to detect dangerous accumulations of gas, but their installation should not be allowed to result in relaxation of precautions to prevent poor practices with gas.

24. Installation and maintenance of pressure-regulating devices should be under the direct supervision of experienced persons.

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25. All gas mains in schools and other public buildings should be installed in well-ventilated places; wherever possible gas mains or headers should be placed outside of buildings.

26. Where gas is used in schools and other public buildings all connections should be permanent and should be made properly by a person or persons competent to do the work in a safe, efficient manner.

27. State supervision and inspection of all public buildings should be provided for the protection of buildings outside the corporate limits of cities.

28. Good "housekeeping" should be the order of the day. All inflammable materials, such as grease, oil, paints, floor dressing, turpentine, and alcohol, should be kept in fireproof lockers. Oily rags and waste should be burned after ~~use or~~ kept in fireproof containers.

29. Schools and other public buildings should be inspected regularly and systematically for fire hazards. Fire-fighting equipment, including fire hose and fire extinguishers, should be kept in first-class condition at all times.

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INFORMATION CIRCULAR

GAS EXPLOSIONS IN BUILDINGS: THEIR CAUSE AND PREVENTION

BY

D. J. PARKER AND C. W. OWINGS

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

GAS EXPLOSIONS IN BUILDINGS: THEIR CAUSE AND PREVENTION[1]

By D. J. Parker[2] and C. W. Owings[3]

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INTRODUCTION

Because of its convenience and availability, natural gas (and to a much less extent manufactured gas) is being used more generally throughout

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the country for domestic and industrial purposes. With this use, specific and little-recognized hazards have arisen owing principally to the fact that the public and the consumer lack knowledge of the explosive property of this fuel.

During the past 8 years gas explosions have occurred in public and private buildings with loss of more than 300 lives and injury to many others. Such appalling catastrophes can and will be prevented if and when the necessary precautions are taken in the construction of buildings and the installation and maintenance of gas lines and gas appliances, plus adequate supervision, inspection, and education.

Many potential hazards have existed unrecognized in industry until revealed by accident. The same condition has existed in the general community supplied with combustible gases.

On request, engineers of the Bureau of Mines have studied thoroughly and comprehensively a number of gas explosions in buildings in various parts of the country, and it is believed that publication of the results of such investigations, with indication of the lessons to be learned and specific recommendations for the prevention of similar occurrences, will be of general value.

This report summarizes the results of these investigations and includes other pertinent data in the hope that in the future definite responsibility will be inescapable on the part of individuals or groups whose duty it is to safeguard the lives of the public, including school children and teachers, from the hazards of gas explosions.

The Bureau of Mines was asked to inspect all the school buildings in Butte and Great Falls, Mont., and the theaters in Butte; 66 buildings were inspected, and the findings are included in this report. The purpose was to ascertain whether construction and maintenance of school buildings approximated those of the New London (Tex.) school that had been involved in an explosion shortly before.

PROPERTIES OF NATURAL AND MANUFACTURED GAS

Before going into detail regarding the several explosions that have been investigated, it appears desirable to discuss briefly the properties of natural and manufactured gas and warning agents used in natural gas.

Natural Gas

Natural gas is tasteless, colorless, and from many sources virtually odorless; it is lighter than air and nontoxic, except when carbon monoxide is formed by incomplete combustion. The specific gravity of natural gases distributed in the larger city of the United States ranges from about 0.60 to 0.68 when compared with a value of 1.00 for air under similar conditions of temperature and pressure. The explosive range when mixed with air is

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from about 4.80 to 15.00 percent; that is, if the percentage of natural gas in air is below 4.80 or above 15.00, the gas-air mixture is nonexplosive. The most violent explosion occurs when approximately 9 percent of gas is present in the gas-air mixture.

Manufactured Gas

Gas manufactured from coal has a characteristic odor disagreeable to most persons, is somewhat lighter than air, and is extremely poisonous because of its relatively high content of carbon monoxide. The percentage of carbon monoxide ranges from about 6 to 12, but 10 percent is believed to be a fair average, except where carbureted water gas is employed. Its poisonous properties can be appreciated better when it is remembered that slight symptoms develop when the concentration of carbon monoxide in the air reaches 0.05 percent, and 0.20 percent is definitely dangerous.

The explosive range of manufactured gas-air mixtures —6 to 36 percent— is much wider than that for natural gas.

In recent years, the manufacture and use of bottled gases have become widespread, and these gases differ in many respects from coal gases. They are odorless or nearly so, are heavier than air, and although they have a narrower range of inflammability (from about 1.0 to 12.5 percent in air) they may be more dangerous, from the explosive standpoint, than coal gases for several reasons.

Malodorants

As natural gas seldom has an arresting odor, and some natural gases and most bottled gases have little or no odor, it is now common practice in several parts of the country to odorize them. This is done by introducing into distribution lines in one or more ways a chemical to impart a distinct odor to such pure gases. According to Weaver,[4] those most commonly used are Calodorant, a complex mixture of organic substances; Pentalarm, chiefly amyl mercaptan; and ethyl mercaptan. The latter has been recommended by the Bureau of Mines as the result of extensive field tests of many warning agents in 1928 and 1929,[5] but neither Calodorant nor Pentalarm had been developed then. The advantages or disadvantages in use of these several compounds may be gathered from the references cited, but the main difference probably is that both Pentalarm and Calodorant have a "gassy" odor, whereas the odor of ethyl mercaptan is not nearly so similar to ordinary oil-refinery odors.[6]

4/ Weaver, E. R., The Odorization of Natural Gas: Am. Gas Jour., vol. 149, No. 1, 1938, pp. 15-18.

5/ Fieldner, A. C., Sayers, R. R., Yant, W. P., Katz, S. H., Shohan, J. B., and Leitch, R. D., Warning Agents for Fuel Gases: Bureau of Mines Monograph 4, 1931, 177 pp.

6/ Henderson, E. L., The Odorization of Natural Gas in the Southwest: Am. Gas Jour., vol. 148, 1938, pp. 29-30.

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These malodorants can be highly effective in indicating leaks in confined spaces but are not very effective in revealing underground leaks unless relatively high concentrations are used. Ethyl mercaptan is perhaps the most effective for this latter purpose and can penetrate through at least 6 feet of earth under favorable conditions. A concentration of 1 to 3 pounds of ethyl mercaptan per million cubic feet of gas is enough to disclose significant house leaks if a dilution factor is not considered necessary, and where used continuously the lower value is said 7/ to be sufficient. For underground leaks, it is desirable to maintain for a few days a concentration of 35 to 50 pounds per million cubic feet. The cost of ethyl mercaptan is about $1.20 a pound at St. Louis, Mo., f.o.b., in quantity lots.

Calodorant appears to be used generally in the Pacific Coast and Mountain States, and it predominates in use in the Eastern States. It is a liquid supplied f.o.b. at the California refinery at about 28 cents a gallon, and 2 gallons per million cubic feet of gas is the concentration most commonly used, although 1-3/4 to 4 gallons per million cubic feet of gas are used in some places or under some conditions. 7/

Pentalarm is used extensively in the Mississippi Valley and Southwestern States. It is a liquid, indicated to cost about 77 cents a pound, and is used in concentrations ranging between 3/4 pound and 3 pounds per million cubic feet of gas. 7/

Even with freight rates from the Pacific to the Atlantic States, Calodorant appears to be the cheapest malodorant, with Pentalarm next, and ethyl mercaptan the most costly of the warning agents commonly used. However, these differences in cost are only wide in certain areas.

There appears to be a difference of opinion concerning the type of odor most desirable for use as a warning agent. The field work of the Bureau of Mines showed conclusively that too many gas consumers were prone to disregard the pleasant or the so-called "gassy" odors as indicating leaks but that if what might be termed disgusting odors that establish conditions commonly referred to as intolerable were thus created, leaks were reported promptly. 8/ For that reason ethyl mercaptan, though more expensive, is still recommended for greater safety. The unpleasant odor did not persist after leaks were repaired; neither did it cause consumer complaints or other trouble in desirably leak-free systems at the time investigations were made by the Bureau, although it should be pointed out that gas appliances were not then provided with pilot lighters, gas-type refrigerators were not used, and the Bureau's tests were only of several weeks' duration or less. The advisability of the Bureau's recommendation

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7/ Weaver, E. R., Work cited in footnote 4.

8/ Fieldner, A. C., Sayers, R. R., Yant, W. P., Katz, S. H., Shohan, J. B., and Leitch, R. D., Work cited in footnote 5, pp. 109, 110, 116, 136, 141-142, 148, 163-164, and 166.

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regarding ethyl mercaptan is indicated by the experience of Port Arthur, Tex., where the vapors from the large oil refineries so permeate the air that it has been found expedient to use ethyl mercaptan rather than Calodorant or Pentalarm as a warning agent.9/

Introduction of Odorants Into the Gas

Methods and equipment used for introducing malodorants into gas-distribution systems are extremely varied and said10/ to cost roughly about 1 dollar per 10,000 cubic feet of daily gas capacity, although such equipment need not be installed in sizes to take care of peak-day capacities.

Liquid odorants may be caused to drip into the main through a needle valve and sight feed-indicator manually controlled, and the methods of introduction range between this, or an even more simple pot-and-wick device for very small demands, up to power-driven proportioning machines that at least two companies manufacture for sale. However, with a little ingenuity satisfactory devices for this purpose can be made from standard parts. The Bureau of Mines publication on gas-warning agents11/ and gas journals illustrate and describe such devices, and all agree that operating costs for this equipment are negligible.

EXPLOSION IN THE POST-OFFICE BUILDING, GLENDIVE, MONT.

On February 12, 1936, at 8:10 a.m., a violent gas explosion occurred in the new post-office building in Glendive, Mont. Eleven persons were in the building at the time of the explosion, three of whom received minor injuries owing largely to flying or falling material, and two were severely burned.

Natural gas in which no malodorant was used at the time of the explosion is supplied to Glendive from the Cedar Creek anticline, about 40 miles to the south.

The building is a one-story brick structure with full basement, the concrete floor of which is laid directly on the ground with no subfloor chambers. To prevent seepage of water underneath the foundation walls and basement floor exterior and interior subdrainage systems are provided.

These drainage systems discharge into a catch basin, thence into a sump, both being in the building below the level of the basement floor. From the sump the water is pumped into the storm sewer, which is at a higher elevation than the sump.

A 2-inch gas line operating at a gas pressure of 30 pounds per square inch was buried 2 feet below the surface of a concrete street pavement, 37 feet from and parallel to the post-office building. Owing to the extremely

9/ Henderson, E. L., Work cited in footnote 6.
10/ Weaver, E. R., Work cited in footnote 4.
11/ Fieldner, A. C., and others, Work cited in footnote 5, p. 139.

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cold weather that prevailed for a month before the explosion this gas main contracted and pulled apart at a point opposite the building. Although the ground in which this pipe was burried was frozen solid the gas traveled laterally 37 feet and downward 8 feet, where it entered the exterior and interior subdrainage systems.

Once in these systems, the gas found its way easily into the catch basin into which these drainage pipes discharged. The catch basin and sump are in a room directly beneath the postmaster's office. This room became filled with gas from the catch basin through a pipe sleeve that carried a steam line to a radiator in the postmaster's office above.

The evidence indicated quite definitely that the source of ignition was a lighted match and that the explosion originated in the postmaster's office.

Because of the intense heat developed in this office and the damage wrought in the building, there is every reason to believe that the accumulation of natural gas was around 9 or 10 percent - the most violent or dangerous explosive mixture of natural gas and air.

To determine whether sewer gas was the explosive agent samples were taken from the subdrainage systems after the explosion and analysis revealed the same constituents as those of the gas supplied to Glendive, samples of which also were analyzed.

The only gas line in this building was a 2-inch low-pressure (6-ounce) line that projected about 1 inch through the rear wall of the boiler room and had no branch lines. This pipe was capped securely to prevent leakage.

The idea is fairly prevalent that if combustible gas is not piped directly into a building - that is, if a building is not serviced - it is more or less immune from gas explosions. This is definitely erroneous. Should a leak develop in a building that is serviced the presence of gas may be detected easily by the sense of smell if a malodorant has been introduced into the gas. On the other hand, should the leak develop outside the building, with consequent lateral migration of the gas into the basement or other chambers, its presence may not be detected by the sense of smell because the action of the ground probably has destroyed the effectiveness of the malodorant.

Conclusions Regarding Glendive Post-Office Explosion

The following conclusions in connection with the explosion at the Glendive post office are based upon both direct and circumstantial evidence obtained by the investigators from eyewitnesses and a thorough and comprehensive study of conditions in and around the post office following the explosion. It is believed, therefore, that the evidence presented in this report is conclusive beyond a reasonable doubt.

1. The explosion originated in the postmaster's office.

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2. Natural gas (largely methane) entered the building from a nearby broken gas main via the exterior subdrainage system and perhaps to a smaller extent through the medium of the interior subdrainage system, both discharging into the catch basin connected with the sump in room 3. The gas then passed through the pipe sleeve, carrying a radiator steam line, into the postmaster's office above.

The ascending current of warm air from the radiator carried the gas to the ceiling of the postmaster's office and, being lighter than air, accumulated next to the ceiling; as it continued to enter the office the layer of gas next to the ceiling became thicker until much if not most of the room from ceiling to floor was filled with an explosive mixture.

3. The explosive mixture was ignited by the flame of a match.

4. There was only one explosion, the flame of which was confined principally to the postmaster's office but extended about 15 feet into the lobby and into the workroom across from the finance section.

The question naturally arises as to why the flame from the explosion did not descend through the pipe sleeve, through which the gas ascended into the postmaster's office, and cause an explosion in room 3. The reason very probably is that the pressure developed by the explosion pressed the floor plate tightly against the floor; this, or possibly the fact that the floor plate, pipe sleeve (which is about 6 inches long), the floor, and the steam line cooled the flame and quenched it before it had time to pass downward through the pipe sleeve into room No. 3.

5. From the standpoint of safety it is poor practice to terminate the discharges of unobstructed, open, unvented subdrainage systems within the confines of a building.

6. In view of the numerous broken gas mains throughout the country during the very severe winter of 1935-36, obviously such mains either should be laid below the frost line or should be provided with suitable expansion joints.

Recommendations in Glendive Case

1. The subdrainage pipes, which discharge into the catch basin and the sump, should be extended downward to within a few inches of the bottom of the catch basin and the sump so that a water seal always may be maintained over the ends of the pipes.

2. Similarly, the opening in the wall between the catch basin and the sump should be provided with pipes extending downward on each side of the partition wall below a definitely maintained water level, so that their ends will be water-sealed at all times.

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3. An automatic signal should be installed to operate when the water in both catch basin and sump drops to a dangerously low level, and it should be some one person's specific duty to see that the proper water level is maintained.

4. The catch basin in the Glendive post office should be vented by a 4-inch pipe extending through the roof and having an airtight manhole cover provided with a gasket and bolted securely in place.

5. In the construction of future Government buildings requiring subdrainage systems similar to those of the Glendive post office the catch basin and sump should be in a properly constructed concrete vault entirely outside the building.

The ideal arrangement would be to have the subdrainage systems discharge directly into a storm sewer without entering the building at all. The elevation of the storm sewer was adverse to such an arrangement at the Glendive post office, hence the necessity for the pump.

6. To prevent blocking during extremely cold weather all vent pipes extending through the roof should be inspected regularly for accumulations of frost or ice.

EXPLOSION BENEATH POST-OFFICE BUILDING STEPS, SPOKANE, WASH.

On January 13, 1937, about 12:30 p.m., a gas explosion occurred beneath the granite steps leading to the main south entrance of the Spokane post-office building, rather severely wrecking them. Three persons were injured - two slightly and one seriously. Fortunately, the steps and sidewalk in front of the building, normally crowded during the noon hour, were almost deserted at the time of the explosion.

This building was completed and occupied in 1909. It is substantially built, with a concrete foundation on which are superimposed large, dressed, granite blocks up to the level of the first floor, limestone having been used for the building proper. A full basement is provided, with no subfloor chambers.

Over all the steps were about 55 feet in length and, including the landings, were approximately 10 feet in width. They were constructed of granite slabs 5-3/4 inches thick, 16 inches wide, and approximately 7 feet long, each weighing about 760 pounds. Each step rested on the step below and projected over the lower step 3 inches, giving a uniform tread of 13 inches, the vertical height or riser of course being the thickness of the slabs.

The steps were divided into three sections by two large granite blocks extending horizontally and at right angles to the building. At each end of the steps the arrangement was similar. The four large granite blocks supported the four lamp standards. Smaller granite blocks supported the large blocks, which, in turn, rested upon brick walls.

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Underneath the blocks supporting the lamp standards were longitudinal channels in the brick walls to carry the conduits to the lights. In these conduit channels also were 1/2-inch gas pipes extending from a point directly underneath the lamp standards through the south wall of the building, into the basement.

Evidently gas had never been turned into these pipes, as the lamp standards were provided with electric-light fixtures only.

The entire step structure was supported by seven concrete beams 13 inches wide, 44 inches deep, and about 9 feet 5 inches long. These beams extend into the south wall of the building, with the other end resting on concrete piers set in the earth. The south end of these beams terminates in a rubble wall bounding the south side of the space beneath the steps.

Brick walls are laid on the concrete beams and the steps and landing slabs rest directly upon them.

The brick walls carrying the two center lamp standards are stepped outward to provide the proper width for supporting the large granite blocks carrying these two lamp standards.

There were six cavities or unventilated chambers beneath the steps. Five of them were 7 feet wide, 9 feet 5 inches long from north to south, and averaged 6 feet in depth. The sixth chamber, at the east end of the steps, was filled with earth to within about 3 feet of the bottom of the landing slab before the original construction of the steps. The total unventilated air space in the six compartments beneath the steps was approximately 2,100 cubic feet.

In the next compartment to the west a 4-inch low-pressure gas-service line enclosed in a two-section 6-inch pipe sleeve passes through this compartment or chamber from south to north and thence through the south basement wall and projects about 2 feet into the basement, where it is closed tightly with a valve. Inby this valve the 4-inch line is reduced to 1-1/2-inch and then to 1/2-inch lines. There was no leakage from these gas lines in the basement, and gas had not been used in the building for several years.

The gas, which is manufactured and distributed to the city of Spokane by the Spokane Gas & Fuel Co., is a mixture of carbureted water gas, coal gas, and a small amount of oil-refinery gas. The mixture is composed of about 1 part water gas to 3 parts coal gas. It has a strong, disagreeable odor, is highly explosive when mixed with air, and has wide limits of explosibility, ranging from 6 to 36 percent.

In addition to its explosive qualities this gas also is deadly when breathed because of the high carbon monoxide content (10 percent, approximate average), 0.5 percent of which is likely to produce unconsciousness and death in a very few minutes.

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Because of the strong, disagreeable, characteristic odor of this gas, warning agents or malodorants were believed unnecessary and were not introduced into it. Upon the basis of odor intensity this gas, as detected by the sense of smell in the basement of the post-office building before the explosion, would, it is believed, rank fourth in the scale and would be described as "strong."12/

On January 12, the day before the explosion, the presence of gas was detected by its disagreeable odor in the basement of the post-office building. Furthermore, on this day the presence of gas was similarly detected in the basement of a store situated on the southeast corner of the block immediately east of the post-office building, some 300 feet away on a straight line from the point of break in the gas main in Lincoln Street.

The assistant custodian of the post-office building reported the matter to the gas company immediately. A crew of men went to work forthwith to find the leak or leaks. After considerable drilling through the pavement, the leak was discovered 12 feet north of the telephone company manhole near the northeast corner of the post-office building. Although it is alleged that the leak was found on January 12 final repairs were not completed until 4 p.m., January 13, or about 3 hours and 30 minutes after the explosion. The repairs were made by applying a Dresser coupling to the broken pipe ends.

Gas was smelled in the pump room at 2 a.m., January 13, by at least two persons. This is significant because the pump room is separated from the reservoir beneath the steps by the south basement wall only. Owing to the situation of the pump room with respect to the points of entry into the basement of the 6-inch steam line and telephone cable it is evident that the leakage of gas into the pump room came through the south basement wall and not through the east wall.

Furthermore, the door of the pump room usually is kept closed, and there are several doors and intervening passages between the pump room and the rooms into which the steam line and telephone cable enter.

Lincoln Street rises on a 3-percent grade from north to south where it parallels the post-office building. The gas, being lighter than air, would tend to flow through the gravel formation and also follow any available openings surrounding pipe lines, sewers, etc., in an effort to escape. In this manner the gas found its way into the cavity beneath the steps.

Just when the break in the gas main occurred is unknown. It may have been several hours or several days from the time the break occurred to the time the odor of gas was first noticed in the basement of the post-office building.

12/ Fieldner, A. C., Sayers, R. R., Yant, W. P., Katz, S. H., Shohan, J. B., and Leitch, R. D., Warning Agents for Fuel Gases: Bureau of Mines Monograph 4, 1931, p. 58.

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The theory that a bomb or other high explosive had been placed beneath the steps and detonated is untenable because there were no openings or vents connecting the space beneath the steps with the outside atmosphere, other than such openings or cracks as may have developed where the mortar or "pointing" had worked out of the joints of the steps as a result of possible expansion and contraction or frost action. It is believed that in this case such openings would not exceed 1/8 inch. Obviously, therefore, it would have been impossible to place high explosives beneath the steps without first providing an opening.

The pressures developed by the explosion, as evidenced by the damage, were fairly uniform in all of the compartments except that at the east end of the steps. This compartment showed less violence because its cubical content was much less than that of the other five compartments.

The uniformity with which the steps were blown both upward and outward toward the street is typical of the action of a gas explosion.

Although most of the steps were broken and one or two of the landing slabs were sheared to some extent there was no evidence of shattering, as unquestionably would have been the case with high explosives.

In view of the foregoing it can be stated confidently that the explosive agent was manufactured gas.

The igniting agent is unknown. The most plausible theory is that a lighted match was thrown on the steps near a small opening or crevice between the steps, through which the explosive mixture was issuing. It is well-authenticated that during the lifetime of the building it has been necessary at times to point, or fill in with cement mortar, the joints of the steps.

As there are no trolley cars in the city and no nearby electrical installations of magnitude, ignition from stray currents would appear unlikely. Furthermore, sparks from hobnails or exposed tacks in the shoe heels of pedestrians, caused by contact with the granite steps, would appear equally improbable, and sparks from a static charge as a medium of ignition is difficult of conception.

Testimony of several employees in the building indicates that the explosion underneath the steps was preceded by an explosion of much less intensity in or near the open manhole at the northeast corner of the building, the interval between the two explosions having been 2 or 3 seconds; this explosion did no damage, and those who heard it were convinced that it was not the back-fire of an automobile.

The theory was advanced that the flame from the initial explosion ignited the gas beneath the steps, causing the second explosion. That the short interval (2 or 3 seconds) between the two explosions was a mere coincidence is borne out by the fact that it would have been a physical impossibility

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for the flame from the first explosion to have traveled some 200 feet through a gravel formation or along possible openings surrounding gas and water lines to reach the point of the second explosion.

It is understood that at the time of the first explosion employees of the gas company were working near the break in the 4-inch gas main, which occurred 12 feet north of the manhole. It is rather singular that no one was burned or otherwise injured as a result of the initial explosion.

During the early stages of the investigation it was believed that an accumulation of gas in the pump room had been ignited by a spark or arc from one of the pump motors, resulting in an inflammation rather than an explosion, and that the flame passed through the space surrounding the 4-inch gas line entering the pump room, thereby igniting the main body of gas beneath the steps.

Although some of the jute packing surrounding the 4-inch pipe was blown into the pump room, subsequent inspections led to the conclusion that the packing perhaps was tight enough around this pipe to prevent propagation of flame from the pump room, through the basement wall, into the reservoir beneath the steps.

Another theory as to the possible source of ignition was that a short-circuit occurred in the wiring leading to the lights on the four lamp standards. It was not difficult to conceive that the spaces immediately beneath the large granite blocks supporting the lamp standards had become filled with gas by leakage through the not very tightly constructed brick walls supporting the large granite blocks. This theory was discarded, however, when the assistant custodian stated that current had not been turned into these lamp circuits for a year or more.

Conclusions Regarding Spokane Post-Office Explosion

In view of the facts ascertained in connection with the investigation of this explosion, the following conclusions appear to be logical, reasonable, and well-founded:

1. The explosion was caused by ignition of a body of gas beneath the steps of the post-office building.

2. The gas involved in the explosion was manufactured.

3. The accumulation of gas beneath the steps of the post-office building was due to a break in a 4-inch low-pressure gas main in Lincoln Street near the northeast corner of the building and outside the post office.

4. The type of gas escaping from the break in the 4-inch low-pressure main was positively identified by its characteristically disagreeable odor in the basement of the post-office building and elsewhere by several postal employees.

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5. The break in the 4-inch gas main was due to contraction of the metal pipe as a result of subzero weather.

6. Unfortunately, the igniting agent could not be determined definitely. The most plausible theory regarding the source of ignition was that a burning match, cigar, or cigarette was dropped on the steps near a small opening in the step joints, from which an explosive mixture was issuing.

7. That there were two explosions appears to be well-established. The first was of much less intensity than the second, and no damage is known to have resulted therefrom.

8. Although the interval between the two explosions was said to be only 2 or 3 seconds it is believed that the time element was a mere coincidence.

9. The initial explosion did not ignite the second; there was no relationship between the two explosions other than the fact that they were both gas explosions.

10. It is believed that the explosion originated near the center of the steps.

11. This manufactured illuminating gas did not lose its malodorant characteristics after migrating through the ground, even for a distance as great as 300 feet.

Recommendations in Spokane Case

To the end that future similar occurrences may be avoided in Spokane and elsewhere, the following recommendations were offered:

1. The open spaces beneath the front steps of this building should be filled completely with earth or other suitable material before the steps are restored.

2. The material used for filling these spaces should be tamped thoroughly during the process of filling to prevent shrinking.

3. The 4-inch gas line entering the pump room through the south wall of the building should be disconnected from the 6-inch main on Riverside Avenue and removed. If this is not done, the small gas lines beneath the large granite blocks supporting the lamp standards should be removed and the connections capped tightly.

4. If the 4-inch gas line entering the basement is removed the aperture left in the wall should be filled completely and solidly for its entire length.

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5. All openings in the basement walls of the building below ground level through which pipes, conduits, cables, etc., enter the building should be sealed tightly enough to prevent gas from entering the building.

6. The assistant custodian should designate some one person to inspect such seals regularly. These seals should be inspected just before the beginning of cold weather and more frequently during the winter. The expansion and contraction of pipes and conduits will tend to loosen and possibly dislodge the sealing material.

EXPLOSION IN OHIO STATE OFFICE BUILDING, COLUMBUS, OHIO

An explosive mixture of natural gas and air that had accumulated in the subbasement of the new Ohio State office building at Columbus was probably accidentally ignited by a match about 2:42 p.m., April 14, 1932. Ten men were killed and 50 injured; property damage was estimated at $500,000 to $1,000,000. Apparently gas from a broken main close to the building found its way into the subbasement. As is usual, even with modern structures, the basement was not and probably would not be ventilated unless some unusual local condition should require ventilation.

At the time of the disaster the building was about 99 percent complete. It had 14 stories above the main floor. Below the main floor was the ground floor, and below it, under the main building, was the basement. Below part of the ground floor were two excavated and enclosed spaces, which were not back-filled; one space communicated with an otherwise enclosed space below the basement of the main building. It was unventilated and completely enclosed except for certain holes around pipes passing through the walls. A 24-inch manhole provided with a cover through the basement floor gave access to the space. A 16-inch gas main had been laid 3 to 4 feet below the sidewalk near the building, and a 57-inch sewer ran under the center of the building.

Immediately before the explosion, 126 persons were in and about the building and 20 city workmen were grading a drive close to it. About 1-1/2 hours before the explosion two bronze workers had cut holes through the concrete floor to the enclosed space. Then they started to cut holes at another place. Meanwhile a foreman had inspected these holes and a carpenter was placing a form under each hole. One of the bronze workers was called there for some purpose. The explosion then took place at the first holes and killed one bronze worker, the foreman, and the carpenter. It is believed that one of the men at the hole, perhaps after lifting the manhole cover nearby, struck a match and thus ignited gas.

After the explosion gas was burning at a curb drain and other places on the nearby drive where city workmen were injured. The top of the subbasement level and the top of the enclosed space on the ground-floor level were blown off. A large steam line above the subbasement was broken, walls were cracked and moved, elevator shafts were badly damaged, and many windows

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were blown out; however, the main structural beams in general were undamaged. One of the high-tension (8,000 volts) wires above the curb drain was severed and gave off arcs and sparks as it struck the ground.

Several weeks before the explosion a break was discovered in the gas line under the sidewalk near the building. After the disaster the gas company stated that there was a break near the curb drain but contended that a block of marble displaced by the explosion had made this break. It was not determined whether there was a direct path for the natural gas from the break in the pipe under the sidewalk to the unexcavated area near the hole in the walls below the ground floor. The enclosed space had not been entered since January 1932, so it easily could have been filled with gas had any seeped into any part of the space below the ground floor and vicinity. Samples of air taken in the space after the explosion did not reveal any gas. There was evidence of an explosion in the sewer below the building.

During litigation following the explosion the gas company contended that before any natural gas was brought to Columbus, gas was ignited frequently around a watering trough that stood on the site of the office building.

Recommendations in Ohio State Office-Building Case

1. Natural-gas mains should not be placed under sidewalks, close to buildings.

2. Medium- and high-pressure gas mains, particularly, should be so welded, coupled, and installed that they will not leak.

3. Wherever possible, buildings should be so designed as not to have closed, unventilated, underground spaces.

4. Floor and walls of buildings with closed or open underground spaces should be made as nearly gastight as possible. Pipes running across such spaces should be enclosed in concrete tunnels or sealed tightly where they pass through the walls.

5. Spaces in buildings below the ground level should be ventilated adequately, preferably by mechanical means.

6. During construction dark spaces should be illuminated with hand flashlights only, preferably of permissible types, and smoking should be prohibited.

7. Sewers should not lie directly under buildings but perferably under streets or other spaces not occupied by buildings; this would not apply if the sewer is in a tunnel with 50 or more feet of solid strata above the sewer.

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TWO GAS EXPLOSIONS, MUNHALL, PA., DECEMBER 5 AND 6, 1929

A gas explosion occurred about 12:40 p.m., December 5, 1929, in the post-office building at Munhall, Pa., on the outskirts of Pittsburgh, Pa. Six lives were lost, and more than 40 persons were injured; the two-story building (22 feet wide and 40 feet long) was completely demolished.

The building was on a foundation that left an excavation of nearly 3 feet under the first floor. The gas main in the street in front of the post office had leaked before, but a rubber patch had been clamped in place. It is presumed that this patch leaked and that the gas followed along the pipe line into the cellar excavation. Presumably the open flame of a gas stove ignited the explosive mixture of gas and air. The force of the explosion struck a passing trolley car, derailing it and injuring several persons.

The following morning the proprietor of a drug store about 50 feet from the post office detected gas fumes and called three plumbers to investigate. As one of the men started to descent to the basement, he turned on the electric-light switch, then saw a spark, followed immediately by an explosion. He and seven others were injured by the blast.

After the explosion, gas was seen to be burning at about 25 places on the street, indicating that the explosion had been caused by gas leaking from a gas main. The gas mains were shut off, and the entire district was without gas for several days until adequate repairs could be made.

The post office had been moved during widening of the street several years before the disaster and, owing to the contour of the ground, was placed on low foundation walls. Like many other public buildings, it had the common defect of an unventilated area under the main floor. Entrance of gas lines, which supplied the fuel for heating the post office, was through the walls and an opening large enough to allow gas from the leaking main to enter the unventilated space. The gas also traveled 50 or more feet and leaked along the gas line into the drug store. Gas burning at many points along the curb indicated its source.

Recommendations were not made by Bureau engineers, but naturally they would have followed closely recommendations made at other disasters discussed in this publication.

EXPLOSIONS IN DWELLINGS AND BUILDINGS

Almost daily newspapers throughout the United States report gas explosions in buildings. Apparently they occur with monotonous regularity, but ordinarily too few persons are injured to attract much attention - only disastrous explosions are given more than passing notice. Many of the smaller gas ignitions should have served as warning of the possibility of more disastrous occurrences, but usually the warning has gone unheeded. The number of deaths and the combined property damage of all the small

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explosions, if assembled as one occurrence, would constitute a catastrophe of very serious proportions.

A few examples of these accidents and the manner of reporting them follow.

An explosion wrecked a new $300,000 Methodist church in Montgomery, Ala., November 29, 1932, killing one workman and injuring another critically. Construction officials said the man who was killed entered the boiler room and struck a match, which ignited gas escaping into the room. Scores of workmen had left the building for lunch a few minutes before the explosion sent the walls crashing to the ground.

Three persons in a Kroger market in Pittsburgh, Pa., escaped without injury on December 13, 1932, when accumulated gas under the widewalk exploded and wrecked the store. A broken gas main had allowed the gas to escape.

A gas explosion wrecked the front of a bakery in Pittsburgh, Pa., on September 29, 1932, seriously injuring the baker when he struck a match to light the oven. Investigators said that gas had leaked into the chamber.

A baker was injured slightly and two plate-glass windows were broken when a gas leak allowed gas to accumulate in a bakery in Mount Lebanon, Pa. July 1, 1937. The explosion occurred when the baker struck a match to light the ovens in the basement.

Five men were killed and four men and three women seriously injured in a gas explosion that ripped out the walls of the Times Spring Co. in Elyria, Ohio, November 9, 1929. According to the Associated Press a flaming column of gas spurted more than 100 feet into the air, and the walls of the plant "crumbled like paper" when a workman entered a gas-filled room in the building and struck a match to light a cigarette. A foreman smelled gas as soon as he stepped into a room; he noticed a man taking a cigarette from a pack, and called to him not to strike a match, but he was too late with his warning and the explosion followed as soon as the match was lighted.

One man was killed and 33 suffered from lacerations, bruises, and burns in the fire that followed an explosion of gas that ripped open a one-story plumbing shop and wrecked several other stores in Detroit, Mich., April 25, 1932. The accumulation of gas was discovered by the crew of a truck while dumping coal into the basement of the shop. Fire-department officials were summoned, but the explosion occurred before the stores and apartments could be vacated. According to police, a defective gas main was broken by the coal-truck crew when they emptied coal into the basement; the escaping gas was ignited by fire in a furnace.

The Pottsville (Pa.) Journal reported the following:

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New York, August 8, 1934. - A gas explosion that sent a ton of brick and mortar tumbling to the street damaged four penthouses on the roof of an 18-story apartment building in Greenwich Village today.

One woman was so badly injured police at first believed her dead. An emergency squad was summoned, however, when a spark of life was detected, and oxygen was applied amid the ruins of the expensive roof-top apartments*****.

Police said that the dying woman was Jeanette Baer, renting agent for the huge building, which houses 125 families. They formed a tentative theory that she had smelled gas leaking in one of the penthouses and had gone to investigate. Possibly she had lighted a match.

An accumulation of gas exploded October 18, 1932, in the cellar of a house at Tacony, a Philadelphia suburb, seriously injuring three men, two of whom were employees of the Philadelphia Gas Works Co. The three men entered the cellar in search of a gas-pipe leak and had reached the foot of the cellar steps when the gas, which had accumulated from a leak in a supply pipe leading from the street, exploded with a terrific roar that shook the neighborhood.

Gov. William G. Conley received burns of the face and hands on November 28, 1932, when gas explosed in the basement of the executive mansion in Charleston, W. Va. The governor had gone to the basement to adjust the furnace. He was thrown 40 feet.

An explosion and fire destroyed a four-room bungalow in Monessen, Pa., on December 18, 1932. The blast was attributed to escaping gas.

A terrific gas explosion injured five persons and nearly demolished a three-story multiple building near Etna, Pa., on December 21, 1932. The cause was a match struck by one of the injured men while looking for leaking gas in the basement. The escaping gas was believed to have come from a vacant house next door, as the greatest damage was done in that house.

A mother and her 8-year-old daughter died in an explosion of gas in Pittsburgh, Pa., July 25, 1933; four other children were uninjured. The woman, who had retired for the night, smelled gas and lighted a candle and, accompanied by her daughter, began to investigate; when she reached the attic, the blast occurred, setting fire to the clothing of both mother and daughter.

It was alleged that gas leaked into a cellar from a defective line in Pittsburgh, Pa., December 28, 1933, and when a door was opened the fumes came in contact with fire in a stove. The resulting explosion injured a woman so severely that she died 2 days later.

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A 75-year-old woman narrowly escaped serious injury when a gas explosion in her Pittsburgh (Pa.) home on February 10, 1933, broke doors and dishes and shattered windows. The explosion occurred in the bathroom.

A Pittsburgh (Pa.) man decided to end his life on Christmas, 1934. He turned on a gas jet in the bathroom of his home and lay down to wait for death. After a few minutes he became nervous and decided to smoke a cigarette while waiting for the gas to take effect. He walked into an adjoining room, lighted a cigarette, and re-entered the bathroom. Just as he was settling himself on the floor again the gas exploded, ripping out sections of the house walls and tossing the man through the door. He was taken to a hospital in a serious condition.

A gas explosion in a New York City apartment demolished two apartments and broke "several hundred" windows. A man turned on four gas jets in the kitchen range and committed suicide. The escaping gas was ignited by a spark from an electric refrigerator motor.

Seven girls were burned in an explosion in a cottage at Ruggles Beach, Ohio, on June 20, 1937. As the girls sat down to breakfast there was a minor explosion in the hot-water heater in the basement, and the basement then filled with fumes. An employee of Ruggles Beach opened the basement door to descend and relight the heater. A moment later there was another explosion, and flames came up a stairway into the dining room. Presumably when the door was opened the fumes came in contact with the stove or were ignited by a match when the employee attempted to light the gas heater.

Three men were injured, one seriously, when an explosion "ripped" through a cellar of a Pittsburgh (Pa.) home on February 19, 1931. The men were in the basement of the home charging a battery, which may have had a defective wire, when the blast occurred. They attempted to extinguish the flames and were burned painfully.

A similar explosion had occurred in the same place February 8, 1931, when one of the men injured in the second explosion lighted a cigarette in the cellar. It was believed gas was responsible for both explosions; no report had been made of the first explosion.

In most of the examples given, gas leaking from gas mains or defective appliances was ignited by matches or by fires in stoves or gas heaters. If the general recommendations given in this publication are followed, most accidents of this type will be avoided.

NEW LONDON (TEX.) DISASTER

On March 18, 1937, at about 3:05 p.m., a disastrous explosion occurred in the main building - the largest of 11 - of the New London (Tex.) school center, causing the death of 294 persons - 280 pupils and 14 teachers.

The school is in Rusk County, in the south-central part of the great East Texas oil field, about 3.5 miles southeast of Overton (the nearest

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town of importance). It is a rural school attended by children from a radius of 15 to 20 miles. All grades from the kindergarten through high school attended, with a total enrollment of about 1,250. The main building, in which the explosion occurred, was used for classrooms for pupils in the higher elementary grades and high school only.

As the details of this disaster have been covered fully in a previous publication of this Bureau[13] only the following brief summary is included here.

Construction

The building was in the form of an "E" and was 254 feet long. It was supported by a reinforced-concrete foundation wall about 12 inches thick, with the first floor of concrete resting on concrete beams supported by concrete piers 12 inches square, which in turn rested upon concrete footings 12 inches thick and 46 inches square placed 3 or more feet below the ground surface. The foundation walls and the concrete floor were poured as a unit. Wooden supports or sills 2 inches square were spaced at regular intervals upon the concrete floor, to which was nailed a diagonal subfloor of pine. A hardwood floor was laid on top of the subfloor.

The walls of the building were of brick, standard size, backed by 8- by 8- by 12-inch 8-cell hollow tile. The roof was of flat tile laid upon wooden sheathing supported on steel trusses and wooden purlins and rafters. Window sashes of steel were set in steel frames.

The concrete floor of the main building was 3 to 5 feet above the ground. This, with the four walls, formed an enclosed space or subfloor chamber, with a volume of about 46,000 cubic feet. Access to this space was by two doors 4 feet square in the rear wall near the north and south ends, respectively. There were also four small 11- by 22-inch openings or ventilators (either glassed in or closed with wire) through the foundation wall, two in the rear and one each in the north and south walls. The door at the north end connecting the manual-training room on the ground floor of the two-story extension of the north wing to the subfloor chamber was said to have been left open as a rule because some of the lumber used in the manual-training room was stored just inside this door beneath the main floor. These openings did not allow enough ventilation to prevent an accumulation of standing gas in the chamber.

Heating System

The building was designed to have a central heating plant, but to reduce cost of operation and maintenance the plans were changed to include individual heating units using natural gas.

13/ Parker, D. J., Jones, G. W., Hill, H. B., and Wade, Gustav, Explosion in School Building at New London, Tex., March 18, 1937: Bureau of Mines Rept. of Investigations 3365, 1937, 29 pp.

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The school was heated by 72 gas-steam radiators individually operated in the several rooms and halls. The radiators, varying in size to suit particular needs, were of a type approved by the American Gas Association Laboratories at Cleveland, Ohio. Care and operation of the radiators were under the direction of a janitor, who lighted the gas radiators in the mornings before school opened and used his own judgment as to the number required to give proper room temperatures.

The heaters were equipped with thermoregulators, which operated on the radiator-temperature rather than steam-pressure principle. The flame acts as a pilot and thus prevents unburned gas from escaping through the radiator and into the flue. If the flame is extinguished while the radiator is turned on gas will continue to flow through the radiator and out into the flue or room until the main gas cock is shut off.

Inspection of the vents from radiators in the rooms that were not damaged badly disclosed that some of the radiators were not vented properly, the vents having been merely led into the hollow-tile walls; others were not provided with vents where they were not accessible.

The radiators were not fastened to the floor and could be moved about with little effort. Such movement may have caused the connections to break below the floor and caused the gas to leak into the chamber; no definite evidence was obtained to support this theory. A janitor stated that the radiators sometimes were moved a short distance during cleaning.

The janitor who lighted the radiators on the morning of the explosion stated that only seven radiators were in operation, five of which were in the halls and two in rooms that were not greatly damaged by the explosion; on the basis of this information, radiators were not in operation in any of the rooms directly over the unventilated chamber in which the explosion originated.

Gas Supply

Natural gas was supplied to the school by a public service company until about January 18 through its own line and meter setting, after which connection was made with a residue-gas line of a nearby producer of gasoline. The gas from the public-service company was not used after January 18, but the pressure regulators and connections were left intact so that service could be resumed if the gas supply from the nearby gasoline company were shut off.

The gasoline company from which the New London school procured its gas has a modern plant for the recovery of butane and gasoline from waste gases in the district. The so-called "wet" gas is gathered in lines and taken to the plant, where the salable products are recovered. The gas is then sent back through pipes alongside the collecting lines to the leases from which the gas originally came, to be used as fuel in boilers or for other purposes.

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It is more or less general practice for persons, schools, and churches near these lines to make connections and use the gas free of charge, because any excess gas not used for heating and power purposes is burned in open flares.

Sometime in February the gasoline company began to recover butane from the gas, which it had not done before that time; therefore, the gas used at the time of the explosion was "drier" than at the time the connection was made in January.

The residue-gas line of the gasoline company passed several hundred yards south of the school building in an east-west direction. Janitors at the school laid a 2-inch line from the school building to the 4-inch gas line and made connection therewith. The significance of the change from dry gas supplied by the United Gas Co. to gas from the gasoline company is whether there was a marked change in the density, heating value, and pressure at which the gas was supplied to the school, insofar as they offered a greater tendency to cause leaks in the gas mains and service connections in the space under the first floor of the school where the explosion originated, or whether this gas produced greater violence on explosion.

Natural Gas Cause of Explosion

The investigation disclosed definitely that high explosives, sewer gas, or seepage of gas or hydrocarbon vapors from nearby oil wells and pipe lines did not enter into the explosion. The remaining source of combustibles, therefore, was the natural gas supplied to the building for heating purposes.

The only evidence contradictory to the general conclusion that the explosion was due to an accumulation of highly explosive natural gas-air mixture in the space under the first floor was given by a janitor at the school, who stated that he entered the space through the door at the south end on the morning preceding the explosion and ignited a match to light a cigarette. He observed nothing unusual, and no explosion resulted when the match was ignited.

This evidence merely shows that at one location in the south end of the space under the floor natural gas in explosive proportions was not present; however, it is not at all certain that appreciable percentages of natural gas were not present there also. A mixture of natural gas in air below the lower explosive limit will not propagate flame but will cause the flame of a lighted match to elongate.

Explosion

The explosion, heard for 12 miles, completely wrecked the entire building directly over or adjacent to the unventilated chamber under the first floor, as well as parts of the two-story buildings attached to the one-story building and the auditorium. Damage to these parts was caused largely by

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the movement of large volumes of gases under pressure following paths of least resistance to the outside atmosphere. After the explosion parts of the auditorium remained standing but were torn down to prevent accident.

A witness at work across the road west of the school building stated there was no flame, but that there was considerable white dust followed by reddish dust after the explosion. He said that the explosion lasted for about 1 second and that the noise was like a rumble or roar, which increased in pitch near the end. Parts of the foundation wall were torn from the ground or, where not torn out, were pushed outward at the top.

Only one small fire occurred at the time or after the explosion, and it was extinguished quickly. Only a few of the victims were singed or burned, and these were at the north end of the building in or adjacent to the manual-training shops. Injuries and deaths were due largely to violence and to crushing caused by the great quantities of concrete, brick, tile, and steel work thrown into the air by the explosion.

Conclusions in Connection with New London Disaster

The following conclusions are based upon direct and circumstantial evidence obtained by the Bureau investigators from qualified persons and a thorough and comprehensive study of conditions existing before and after the explosion:

1. The immediate cause of the disaster was ignition and explosion of a large volume of highly explosive natural gas-air mixture that had accumulated in an unventilated space beneath the first floor of the main school building.

2. The gas was present in the space because of leakage from gas lines and their fittings (possibly a broken service connection) suspended beneath the floor, with no method provided to detect the gas or remove it by natural or forced ventilation.

3. The physical evidence indicates that higher concentrations of natural gas were present in the north section of the space beneath the first floor and suggests that the leakage took place in that part of the subchamber.

4. Natural gas did not seep through the soil from adjacent gas lines or wells.

5. Liquid hydrocarbons (crude petroleum and gasoline and their vapors) from surrounding wells and pipe lines were not responsible for the explosion.

6. Although the composition of gas supplied to the building at the time of the explosion varied from time to time the pressure on the line was relatively constant and moderate, and no appreciable difficulty should

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have resulted from the use of the gas. The investigation revealed that the gas line that supplied the gas to the building was provided with traps to eliminate condensate and oily material and thus provide a satisfactory supply of gas for the purpose.

7. Manipulation of an electric switch on a panel in the manual-training room near an open door leading into the north end of the unventilated region under the first floor ignited the gas, and the physical evidence shows that the explosion propagated in a southerly direction through the chamber.

8. Explosive mixtures of natural gas in air from the space under the first floor encompassed the switch panel probably in large part because of a drop in barometric pressure on the afternoon of the explosion and the simultaneous increase in atmospheric temperature, which caused the gas in the space to expand, forcing excess gas from the space through the open door. The explosive mixture issuing from this opening either was deflected or was carried to the switch by minor air currents and was ignited by a spark or arc when the switch was manipulated. The flame was carried through the door into the space underneath the floor.

9. The evidence does not indicate that the individual heating units on the first floor of the building ignited the explosive mixture. However, these heating units may have been involved in the formation of the explosive mixtures as they were moved about, and this may have broken a gas connection in the space below the floor.

10. This large volume (possibly as much as 46,000 cubic feet) of an ignited explosive mixture of gas and air was in an enclosed and substantially confined space, with little or no opportunity for expansion at low pressure. Hence, maximum opportunity was afforded to build up a high pressure as the explosion wave progressed, resulting in widespread disrupting and destructive effect.

11. Because the explosive natural gas-air mixture appeared to be uniformly mixed, as evidenced by the violence of the explosion over the entire space under the first floor and the absence of flame and black smoke when the mixture exploded, the conclusion is warranted that the accumulation was due to relatively small leaks rather than to a large leak.

12. Obviously it is a grave mistake to allow unfilled or unventilated spaces to remain beneath the floor of any building where combustible gas or vapors may accumulate, either from mains underneath or from seepage through or under the foundation walls from outside sources.

Recommendations in Connection with New London School Disaster

The lessons learned from this explosion warranted the following recommendations, which, if complied with, should in a large measure prevent similar tragedies in future.

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1. All schools and other public buildings should be constructed so that there are no unventilated, relatively inaccessible, enclosed spaces or chambers, especially in the basement region, under or near recitation or assembly floors. Wherever possible the first floor should be laid directly on the ground; where this type of construction is impossible spaces between the floor and the ground should be filled with earth or other material, thus making impossible the accumulation of explosive mixtures underneath the floors.

2. School buildings and other public buildings that have unventilated basements, chambers, tunnels, or other spaces under floors and steps, and attics should be provided at all times with adequate, constant ventilation.

3. Suitable warning agents with distinct odors introduced into fuel gases that have little or no odor of their own have proved of great assistance in detecting leaks in public buildings and private homes. Although use of malodorants is only one factor to be considered in providing adequate protection (as explosions have occurred with mixtures of air and manufactured gas, which has a distinct odor), fuel-service installations should be studied, especially in school and other buildings where the public assembles, to determine the need for impregnating the gas with an agent that will warn against leakage.

4. Alarm systems based upon instruments that detect the presence of inflammable gas and bring the existence of dangerous concentrations of combustibles in confined spaces to the attention of officials in charge of school buildings have value but do not solve the problem. Efforts should be made to eliminate the causes, thus making the alarms unnecessary.

5. All gas (and electrical) lines serving schools and other public buildings, and all piping, connections, fixtures, appurtenances, and appliances in such buildings should be of permanent construction, placed by competent persons in accordance with the latest approved fire underwriters' or other applicable specifications and operated in accordance with known safe practices; moreover, they should be kept in repair at all times. Where individual heater systems are used the individual heating units should be fastened rigidly to the floor.

6. Responsibility for the construction, maintenance, and operation of gas pipe lines serving the public, and especially for the regulation of pressures in such lines, should be under the exclusive control of persons or organizations experienced in such work. Schools that use gas for heating or other purposes should purchase their fuel supply from a public service company that, through experience and regulation, may be expected to give a more uniform supply of gas and thus a better and safer service than can be obtained from a residue gas line not operated to supply the kind of service that is required.

7. Responsibility for the testing, lighting, and general care of the entire heating system should be entrusted only to persons who are familiar with such systems and competent to handle them safely and efficiently.

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8. All gas mains to schools and other public buildings should be installed in well-ventilated places, and advantages in safety may be gained by placing gas mains or headers outside buildings, thereby minimizing the hazard of gas leakage in enclosed spaces.

9. Accordingly, provision should be made to seal all openings where pipes pass through walls.

10. Central heating systems with the heating plant isolated in a separate structure have definite advantages with respect to protection against fires, explosions, and carbon monoxide. They also have certain advantages in efficiency with respect to large public buildings. It must be considered, however, in planning a heating system, that gas usually is required in some parts of school buildings for cooking, hot-water supply, and chemical and other laboratories, and adequate precautions should be taken in connection with these as well as with heating.

11. A State supervisory body should inspect structures and buildings in which the public assembles and which are outside the corporate limits of cities and towns where municipal safety inspection is in effect. Safety inspection by State or municipal agencies should extend not only to the construction of school and other public buildings but also to plans and design of such buildings and should include structural features as well as details of heating and ventilation.

12. In rural districts where school buildings are not subject to regulated inspection gas companies may be of great service in this campaign of safety through their knowledge of and familiarity with the hazards involved in the use of gas. They should make periodic inspections and offer constructive suggestions for the safe use of gas on premises served by them. If these suggestions are not followed gas service to the buildings should be stopped immediately until the proper corrections for safety are made.

INSPECTIONS IN SCHOOLS AND OTHER BUILDINGS OF BUTTE AND GREAT FALLS, MONT.

The appalling loss of life in the New London (Tex.) school explosion aroused grave public concern as to whether conditions similar to those at the Texas school before the explosion might exist in other school buildings in towns using natural or manufactured gas.

Following a request by the Hon. J. J. O'Connell, Montana State congressman, the Director of the Bureau of Mines assigned an engineer to inspect all school buildings in the cities of Butte and Great Falls, both of which use natural gas.

These two cities were selected because five gas explosions had occurred in buildings in Butte between February 1 and June 1, 1937, and one had occurred in Great Falls in 1936. Fortunately, no lives were lost.

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The inspection, which began on April 7, 1937, lasted 15 days and included 12 parochial institutions, 21 public schools, 1 business college, 6 Montana School of Mines buildings, and 6 theaters in Butte and vicinity, and 6 parochial institutions and 14 public schools in Great Falls - a total for both cities of 66 buildings.

The object of the inspection was to determine whether there were hazardous conditions, such as unventilated chambers or dead-air spaces, beneath the basement or first floors of these buildings to serve as reservoirs for gas accumulations in the event of gas leakage either within or outside the buildings beneath the surface of the ground. To determine the presence of gas leakage through the ground from nearby mains or from gas lines, meters, regulators, and gas appliances in the buildings, approximately 1,350 readings were taken with combustible-gas detectors of recognized accuracy and dependability. Only one reading revealed the presence of combustible gas.

Thirty-four of the 46 buildings inspected in Butte and 18 of the 20 inspected in Great Falls had unventilated subfloor chambers.

In view of the potential explosion hazards of such conditions, the situation seemed to demand immediate drastic action by those charged with such responsibility.

Fire-fighting equipment, including fire extinguishers of different types and fire hose, in many instances was substandard in Butte schools, but with few exceptions such equipment was in first-class condition in the Great Falls schools. A malodorant with a characteristically disagreeable odor is used in the gas supplied to Butte and Great Falls. This odorant is apparently highly efficient where a leak occurs inside buildings.

Because of the definite explosion hazard existing in most of the buildings inspected the necessary remedial action was urged upon those charged with responsibility for safeguarding the lives of both students and teachers.

EXPLOSION IN SCHOOL BUILDING, BARBERTON, OHIO.

An explosion of natural gas occurred about 1:30 p.m., May 31, 1939, in an old frame dwelling used temporarily as a school building at Barberton, Ohio. There were 101 pupils, 6 and 7 years old, and 4 adults in the building; 57 suffered more or less severe injuries, but there were no fatalities.

About 2 weeks before the explosion the janitor had detected a gas odor in the basement and he was ordered to shut off the gas at a meter cock inside the basement; the gas company was not notified of the action taken. A leak had developed in a 1 1/4-inch gas line about 3 1/2 feet from the foundation in the ground outside the building; the leaking gas evidently followed the gas pipe, passing through loose earth and the foundation into the cellar.

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The janitor had placed waste paper in the hot-air furnace, had lighted it, and was on the way to the stairs when the flame from the fire ignited the gas. The resulting explosion pushed out the entire lower north and south walls. The east (rear) and west (front) walls and the upper part of the north and south walls remained standing. A brick chimney and stair wall apparently helped sustain the roof and floors, which probably prevented any fatalities.

The building, which was in a dilapidated condition, was to have been razed at the end of the school year and had been purchased with that idea in mind. Thus, it was unfit to serve even temporarily as a school building, but as it was so used and there was no need for gas in the building, the supply should have been cut off at the curb. Despite failure of school authorities to notify the gas company, who would have cut off the service line when a leak was noted 2 weeks previously, and although a new sewer excavation had uncovered the service line, it was again covered by new fill.

This explosion again shows the hazard of leaking gas and indicates that at least one safe procedure is to notify the local gas company whenever a leak is suspected. Until leaks have been repaired open lights, fires, and electric current should not be allowed near the suspected source of gas.

LESSONS TO BE LEARNED FROM GAS EXPLOSIONS IN BUILDINGS.

A careful study of the gas explosions that have occurred in buildings in the last few years reveals that in many instances unventilated chambers, rooms, or subfloor spaces formed ideal reservoirs for accumulated gas.

Much can be done to prevent these explosions by educating consumers and the public generally to the dangers of gas leakage and proper maintenance of gas appliances, including inspection and supervision.

Immediate research work should be done on the problem of developing and using a malodorant that does not lose its effectiveness where gas leakage from street mains migrates laterally through the ground into buildings or other places where it may accumulate.

As long as the practice of burying gas lines beneath street surfaces continues the hazard of leakage from gas lines buried at shallow depth in northern latitudes will continue to be greater during the winter and the explosion hazard accentuated because basements must of necessity be kept closed tightly. If at all possible, gas lines in trenches should be laid below the freezing zone, using pipe coated with corrosion-resisting material. Some authorities claim that gas lines should be laid above ground to provide inspection and to permit easy escape and air dilution of leaking gas.

Furthermore, the likelihood of gas explosions is increased manyfold where gas lines, meters, and regulators are installed in unventilated subfloor chambers.

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Inspection of the schools in two medium-size cities disclosed the alarming fact that a potential gas-explosion hazard existed in most of these buildings because of presence of unventilated subfloor chambers in structures in which gas was used.

The elimination of such hazards will require the wholehearted cooperation of city authorities, school boards, and the gas companies.

Each building presents a separate problem, and whether or not the proper ventilation of subfloor spaces resolves itself into vents to the outside atmosphere, a series of ventilating stacks, or even a separate ventilating system of blower fans will require the technical advice of a competent ventilating engineer who has a knowledge of gases, especially explosive gases.

SUMMARY OF RECOMMENDATIONS

1. Natural gas, which is largely methane, does not have an arrest-odor and is tasteless, colorless, lighter than air, and nontoxic. The explosive range is 4.80 to 15.00 percent in air, the most explosive point being at about 9 percent in air.

2. Manufactured gas generally has a distinct odor, is lighter than air, and is extremely poisonous owing to its high content of carbon monoxide, which averages about 10 percent except when carbureted water gas is employed, when the carbon monoxide content may be as high as 25 percent.

3. Carbon monoxide causes slight symptoms with as little as 0.05 percent, and a concentration of 0.20 percent is definitely dangerous.

4. Unless natural gas has a distinct odor it should be odorized, preferably with a malodorant or stench that retains its warning properties after passing through the ground.

5. Ethyl mercaptan is one malodorant shown by extensive field tests to have most of the desirable qualities of a warning agent, unless it be that of cost, and if used continuously in gas-distribution lines in a concentration of 1 to 3 pounds per million cubic feet of gas it can give warning of leaks in enclosed spaces (houses).

6. After house leaks have been disclosed by the lower concentration and repairs have been made, a concentration of 35 to 50 pounds per million of ethyl mercaptan has been found of great help in locating underground leaks.

7. Surveys for underground leaks need to be made only at relatively long intervals, and the higher concentrations need to be maintained only for short periods if enough trained personnel is available to do the work.

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8. It is poor practice to terminate discharges of unobstructed, open, and unvented drainage systems within a building.

9. Gas mains should be laid below frost level and/or be provided with expansion joints, or they should be laid on the surface.

10. Subdrainage pipes discharging into catch basins or sumps should be extended below the water level to form a water seal at all times.

11. Sumps and catch basins should be vented to the top and outside of the building and, wherever possible, should discharge directly into storm sewers. They should also be in a concrete vault outside of the building.

12. All openings in basement walls below ground level through which pipes, conduits, cables, etc., enter a building should be sealed to keep gas from following them into the building.

13. Gas mains should not be placed under sidewalks or steps but at a greater distance from buildings; they should be so welded, coupled, and installed that the likelihood of leaks occurring will be reduced to a minimum.

14. Buildings, including steps leading to them, should not have closed underground spaces, but where such spaces exist the floor and walls should be made as nearly gastight as possible. Pipes running across such spaces should be enclosed in concrete tunnels or sealed tightly where they pass through walls.

15. Spaces in buildings below ground level should be adequately ventilated, preferably by mechanical means.

16. During construction or inspection as to gas troubles dark spaces should be illuminated by permissible flashlights; smoking, lighting of matches, or use of other open lights should be prohibited. Further efforts should be made to educate the public to such hazards.

17. Sewers should not be directly under buildings unless at least 25 feet of solid strata separate the top of the sewer from the lowest part of the building.

18. Whenever the odor of gas is detected electric switches should not be turned off or on, but electric current should be shut off at some safe point beyond the suspected area, and matches or other sources of flame should not be allowed near rooms or areas from which the odor emanates.

19. During construction of buildings all lights, fires, and other sources of flame or electric arcs should be prohibited in the basement or similar places where gas is likely to escape from the time workmen

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start to bring gas lines near or into the building until the work has been completed and the plumber or person directly in charge has approved the installation.

20. In large establishments where men work in basements or other rooms where gas is likely to accumulate tests for gas should be made by a competent employee before workmen are allowed to enter at the beginning of a shift.

21. Gas companies should be notified as soon as leaks or evidence of leaks are discovered; frequently fires and explosions may be prevented by turning the gas off at the curb.

22. Switches to control lights and other electrical equipment in unventilated spaces should be placed outside the enclosures or should be of a type approved for use in explosive atmospheres.

23. Schools and other public buildings that have unventilated basements, chambers, tunnels, or other spaces under floors and steps and attics should be provided at all times with adequate, constantly functioning ventilation.

24. Where warning agents are not used continuously in the gas supplied by the local gas company, restricted areas should be tested periodically. If this procedure is not followed, tests for leaks of gas should be made in public buildings by competent persons at least once a month by introducing a warning agent into the gas where it enters the building.

25. Alarms for combustible gas also may be used to detect dangerous accumulations of gas, but their installation should not be allowed to result in relaxation of precautions to prevent poor practices with gas.

26. Installation and maintenance of pressure-regulating devices should be under the direct supervision of experienced persons.

27. All gas mains in schools and other public buildings should be installed in well-ventilated places; wherever possible gas mains or headers should be placed outside buildings.

28. Where gas is used in schools and other public buildings all connections should be permanent and should be made properly by a person or persons competent to do the work in a safe, efficient manner.

29. State supervision and inspection of all public buildings should be provided for the protection of buildings outside the corporate limits of cities.

30. "Good housekeeping" should be the order of the day. All inflammable materials, such as grease, oil, paints, floor dressing, turpentine, and alcohol should be kept in fireproof lockers. Oily rags and waste should be burned after use or kept in fireproof containers.

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31. Schools and other public buildings should be inspected regularly and systematically for fire hazards. Fire-fighting equipment, including fire hose and fire extinguishers, should be kept in first-class condition at all times.

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